



2021 Issue 2 // Volume 117

# THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

Modeling of organic semiconductor conduction parameters with reference to inorganic semiconductors

Modeling of organic semiconductor metallic contact and optoelectronic parameters with reference to inorganic semiconductors

A review of Schottky junction solar cells

Register now for our Graduation Celebration

2020 Outstanding Chapter Award Winners

Celebrating 50 Years with IEEE-HKN

IEEE-Eta Kappa Nu



## *Advances in* **SOLAR CELL** *Design*





## IEEE-HKN AWARDS PROGRAM

As the Honor Society of IEEE, IEEE-Eta Kappa Nu provides opportunities to promote and encourage outstanding students, educators and members.

Visit our new website to view the awards programs, awards committees, list of past winners, nomination criteria and deadlines.

### ALTON B. ZERBY AND CARL T. KOERNER OUTSTANDING STUDENT AWARD (OSA)

Presented annually to a senior who has proven outstanding scholastic excellence and high moral character, and has demonstrated exemplary service to classmates, university, community, and country.

**(Deadline: 30 June)**

### C. HOLMES MACDONALD OUTSTANDING TEACHING AWARD (OTA)

Presented annually to electrical engineering professors who have demonstrated, early in their careers, special dedication and creativity in their teaching, as well as a balance between pressure for research and publications.

**(Deadline: Monday after 30 April)**

### DISTINGUISHED SERVICE AWARD

Recognizes members who have devoted years of service and lifetime contributions to Eta Kappa Nu (or IEEE-HKN), resulting in significant benefits to all of the Society's members.

**(Deadline: Monday after 30 April)**

### OUTSTANDING CHAPTER AWARD (OCA)

Recognizes chapters for excellence in activities and service at the department, university and community levels. The award is based on the content contained in their Annual Chapter Report for the preceding academic year.

**(Deadline: 31 July)**

### OUTSTANDING YOUNG PROFESSIONAL AWARD (OYP)

Presented annually to an exceptional young engineer who has demonstrated significant contributions early in their professional career.

**(Deadline: Monday after 30 April)**

### IEEE-HKN ASAD M. MADNI OUTSTANDING TECHNICAL ACHIEVEMENT AND EXCELLENCE AWARD

Presented annually to a practitioner in the IEEE technical fields of interest who has distinguished himself or herself through an invention, development or innovation that has had worldwide impact.

**(Deadline: Monday after 30 April)**

## IEEE-Eta Kappa Nu Board of Governors

### President

Ronald Jensen

### President-Elect

James Conrad

### Past President

Edward Rezek

Jason Hui

*Governor, Regions 1-2*

Michael Benson

*Governor, Regions 3-4*

Christopher  
Sanderson

*Governor, Regions 5-6*

Lorena Garcia

*Governor, Regions 7-10*

### Governors

Preeti Bajaj

*Governor At-Large*

Ryan Bales

*Governor At-Large*

Hulya Kirkici  
*Governor At-Large*

Sean Haynes  
*MGA*  
*Governor At-Large*

Sandro Sartoni

*Student Governor*

Joseph Greene

*Student Governor*

### Treasurer

Karen Panetta

### Secretary

Bernard Sander

### Director

Nancy Ostin

### Program Manager

Stacey L. Bersani

IEEE-Eta Kappa Nu (IEEE-HKN) was founded by Maurice L. Carr at the University of Illinois at Urbana- Champaign on 28 October 1904, to encourage excellence in education for the benefit of the public. IEEE-HKN fosters excellence by recognizing those students and professionals who have conferred honor upon engineering education through distinguished scholarship, activities, leadership, and exemplary character as students in electrical or computer engineering, or by their professional attainments. *THE BRIDGE* is the official publication of IEEE-HKN. Ideas and opinions expressed in *THE BRIDGE* are those of the individuals and do not necessarily represent the views of IEEE-HKN, the Board of Governors, or the magazine staff.

Copyright © 2020 IEEE. All rights reserved. Internal or personal use of this material is permitted with credit to the original source. Parties interested in reprinting or republishing IEEE material for advertising or promotional purposes or for creating new collective works for resale or redistribution must obtain permission.

Get in touch with Eta Kappa Nu [Twitter: ieee\\_etakappanu](#) [Facebook: IEEE-HKN](#)



THE BRIDGE

# THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

2021 ISSUE 2 | ADVANCES IN SOLAR CELL DESIGN

**4**

## Editors-in-Chief

Dr. Sahra Sedigh Sarvestani  
and Dr. Steve E. Watkins

**5**

## Guest Editor

Dr. Amirhossein Ghods

## Features

**14**

Modeling of organic semiconductor conduction parameters with reference to inorganic semiconductors

**20**

Modeling of organic semiconductor metallic contact and optoelectronic parameters with reference to inorganic semiconductors

**27**

A review of Schottky junction solar cells

## Departments

**6**

### CHAPTER NEWS

IEEE-HKN Debuts Successful Practices Database

Consolidating Student Groups to Strengthen Research and Innovation Opportunities

**8**

### CHAPTER NEWS

Toy Adapt-a-thon Uses Basic Circuit Knowledge to Create Holiday Joy

Mu Beta Chapter's Kidzineers STEM Outreach Program

**10**

### DONOR PROFILE

Harnessing Strength in Numbers  
Lyle Feisel, Ph.D.

**11**

### IEEE-HKN ANNIVERSARY

Congratulations, John McDonald, IEEE-HKN for 50 Years

**12**

### AWARD SPOTLIGHT

Congratulations, 2019-2020 Outstanding Chapter Award Winners

**13**

### ECEDHA CORNER

ECEDHA and IEEE-HKN Partner for Student Success

2021 Outstanding Student Award Applications Due 30 June

**33**

### SOCIETY SPOTLIGHT

IEEE Solid-State Circuits Society: Shaping the IC and the Electronics World

**34**

### PARTNER SPOTLIGHT

Texas Instruments and IEEE-HKN Workshops Engage with Remote Engineering Students

**36**

### STUDENT PROFILE

Hannah Schroeder

**39**

### HISTORY SPOTLIGHT

*THE BRIDGE* Magazine of IEEE-Eta Kappa Nu Part II

**42**

### IN MEMORIAM

Innovator in Electronic Displays  
Lawrence E. Tannas Jr.

Former HKN  
National President  
John E. Farley

### Editors-in-Chief:

Sahra Sedigh Sarvestani  
and Steve E. Watkins

### Editorial Board Members:

Emily Hernandez, Marcus Huggans,  
Hulya Kirkici, Zahra Manzoor,  
and Emmanuel Oyeekanlu

**Managing Editor:** Nancy Ostin

### Assistant Managing Editor:

Stacey L. Bersani

**Advertising Sales:** Christine Cherevko

[c.cherevko@ieee.org](mailto:c.cherevko@ieee.org)

**Design Company:** [Tumbleweeds, LLC](http://Tumbleweeds, LLC)

### IEEE-HKN INTERNATIONAL HEADQUARTERS

**Editorial inquiries:** IEEE-Eta Kappa Nu,  
445 Hoes Lane, Piscataway, NJ 08854, USA  
US Toll Free: +1 800 406 2590  
Outside US: +1 732 465 5846  
Email: [info@hkn.org](mailto:info@hkn.org) | [www.hkn.ieee.org](http://www.hkn.ieee.org)

Subscription address and email changes: IEEE Contact Center

US Toll Free: +1 800 678 4333 | Outside US: +1 732 981 0060 | Fax: +1 732 562 6380 | Email: [contactcenter@ieee.org](mailto:contactcenter@ieee.org)





Dr. Sahra Sedigh  
Sarvestani

Beta Chapter



Dr. Steve  
E. Watkins


Gamma Theta Chapter

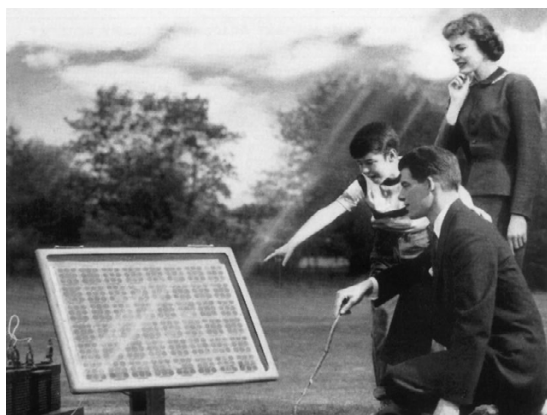
## *THE BRIDGE*, May 2021 Letter from the Editors-in-Chief

Dear IEEE-Eta Kappa Nu Members and Friends,

This issue of *THE BRIDGE* magazine highlights current research in solar cell design. We appreciate the efforts of our guest editor Dr. Amirhossein Ghods and the other authors. It is impossible to overstate the importance of developing photovoltaic technology to address renewable and off-grid energy needs. These global research efforts reflect an appreciation for improving technologies with respect to both performance and fabrication. Innovations that provide higher operational efficiencies and lower manufacturing costs are essential for growth in the use of photovoltaic energy technology.

The semiconductor solar cell was developed as a result of research at Bell Telephone Laboratories. In 1940, Russell S. Ohl discovered the semiconductor  $p-n$  junction and observed that light produced a small electrical current. Further work by the Bell Labs team of Daryl Chapin, Calvin Fuller, and Gerald Pearson led to the "Bell Solar Battery" with an efficiency of about six percent. The demonstration of this first practical silicon solar cell was in 1954. Technical development and commercialization have proceeded since.

We welcome your feedback and remind you that *THE BRIDGE* is available on the IEEE app as well as the [magazine website](#). Each issue has a variety of technical features, Chapter news, alumni notes, etc. If you enjoy this issue, please check out the archive index of prior features on [page 39](#). The editorial board can be contacted by e-mail at [info@hkn.org](mailto:info@hkn.org). 




*Bell Solar Battery*

## Letter from the Guest Editor

*By Dr. Amirhossein Ghods*

Photovoltaic devices are an attractive and durable source of energy, especially in areas with long hours of continuous sunshine and relatively stable meteorological conditions. Major programs have been launched across the world to utilize and optimize the use of this natural resource, from the U.S. Department of Energy's SunShot initiative to the Lighting Africa program founded by the singer/rapper Akon. Research by the World Bank and the International Finance Corporation indicates that more than 32 million people in Africa are currently meeting their basic electricity needs through off-grid solar products. This level of solar energy usage is the CO<sub>2</sub>-equivalent to taking 383,745 cars off the road for a year.

In recent years, the general perspective toward photovoltaic devices has substantially changed from inefficient, bulky, and expensive to more efficient, smaller, and more cost-effective devices. Solar cells made from semiconductors other than silicon have shown promising results, such as notably higher practical power conversion efficiency and easier fabrication processes. Moving beyond single-junction devices has also opened the door to highly efficient devices that capture a much larger portion of the solar spectrum than conventional silicon-based solar cells.

In this issue, we review applications of organic and inorganic semiconductors that can be used in photovoltaic devices. The concept of metal-semiconductor junction is introduced and explained from both modeling and simulation perspectives, as well as the practical device fabrication viewpoint. Metal-semiconductor junctions have shown great promise in replacing current p-n junction solar cells. In other words, a simpler and more cost-effective fabrication process, in addition to the potential to achieve higher power conversion efficiency, have made metal-semiconductor junction solar cells an attractive choice for use in developing markets and economies. It is the objective of this issue to demonstrate global efforts being made to study new materials and structures that can be used in solar cells to achieve higher efficiency and easier production. 



Dr. Amirhossein Ghods


Park Systems, Inc

# IEEE-HKN Debuts Successful Practices Database

## Chapters Officers, Get Inspired

Are you looking for new activities and initiatives to do with your Chapter? Check out our [Successful Practices Database](#)! Using the activity reports submitted by our Chapters, IEEE-HKN has constructed a searchable and sortable database of activities for programming, recruiting, fundraising, and community service ideas that is available to all Chapter leaders. Only current Chapter leaders can access the database, so be sure to update your [Chapter Officers](#) and Advisors.

## Volunteers, Here is a New Opportunity for You

Interested in helping build up the database? We are currently seeking volunteers to review and format activities! To find out more, read the [position description](#) and fill out the [Reviewer Application](#). 



## IEEE Learning Content at Your Fingertips

Check out the IEEE Learning Network (ILN) for hundreds of hours of online learning courses from across IEEE, taught by industry experts

**Visit [iln.ieee.org](http://iln.ieee.org)  
and start learning today!**

**Stay up to date with the latest discounts:  
[innovationnetwork.ieee.org/whats-new](http://innovationnetwork.ieee.org/whats-new)**

# Consolidating Student Groups to Strengthen Research and Innovation Opportunities

*Submitted by Cesar Vargas-Rosales, Faculty Advisor  
Lambda Rho Chapter, Tecnologico de Monterrey, Mexico*

The Lambda Rho Chapter of IEEE-HKN together with the IEEE ComSoc Monterrey Chapter have focused on creating a constructive and nurturing environment for undergraduate and graduate students at Tecnologico de Monterrey in Mexico.

One initiative has been the organization of students in dedicated groups with hands-on activities for research and innovation. This is mutually beneficial: First, it creates an environment where students can develop their own abilities and skills; and second, it gives researchers a chance to develop solutions to problems with practical character. In any case, the initiative helps promote the IEEE-HKN Chapter, the group, and the projects throughout the academic community resulting in an increased interest in participating in the group.

At Tecnologico de Monterrey, we have worked for three years to establish, implement, and consolidate a group of students and professors into a program



Figure 1. Founders of Space Makers and Mixcoatl Project members  
(video in Spanish <https://www.youtube.com/watch?v=KfPVefXeb0g>)



called Space Makers. The program promotes student participation in inspiring and interactive learning experiences to address challenges and to develop disciplinary and cross-disciplinary skills.

The group initially concentrated in the development of satellite systems and communications projects.




Figure 2. Hands-on action and design

The group participated with project proposals for the Mexican Space Agency in 2019. Also, the group developed an organization of its own, with three basic areas: Satellites, Rovers and Rocketry. Mentors from industry or academia, even from international companies or organizations, are part of each area. Space Makers established contacts with CONAE Argentina, NASA, Samara University in Russia, and Japan to create opportunities toward potential graduate programs and research stays.

The group has also seen the strong need to promote STEM initiatives and is implementing a women-only program for its members called Space Girls, with the main objective of addressing the fifth sustainable development goal of the United Nations, gender equality.

Space Makers is always seeking new initiatives for the student members. Sometimes those come as short stays at different companies, or yearlong projects, such as AztechSat II nanosatellites with NASA, or the Intercollegiate Rocket Engineering Competition (IREC). One of these initiatives was the SPES Project, where the group participated in a worldwide competition organized by Airbus and UNOOSA with a design of a space mission for a 3-unit CubeSat that aimed to dock in the Bartolomeo module located in the International Space Station (ISS). The nanosatellite design was made from scratch, and it was extremely challenging. The students developed their research abilities and skills for organization, teamwork, positive leadership, effective communication, problem-solving, critical thinking, and working under pressure. The work was based on procedural learning with the method of lean start-up.

Currently, Space Makers is working with Keysight Technologies for a pilot group to get a certification in IoT this year. The final goal is to have an IoT certification within the senior year of the Electronics Engineering undergraduate program by 2022. 

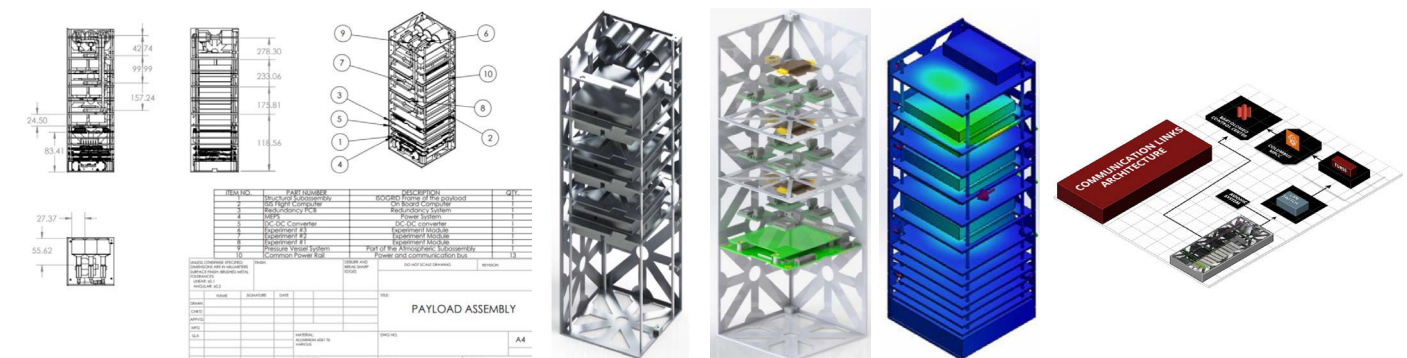


Figure 3. Development of CubeSat for Project Bartolomeo

# Toy Adapt-a-thon Uses Basic Circuit Knowledge to Create Holiday Joy

*Submitted by Jerika Cleveland, Chapter President  
Gamma Tau Chapter, North Dakota State University*

In the final months of 2020, members of the Gamma Tau Chapter at North Dakota State University became elves who hack as they worked with the university's Disability Services department to modify electronic toys for children with special needs.

The Chapter's first ever Toy Adapt-a-thon, where engineers created audio jack connections in parallel to the buttons on toys, enabled children with motor disabilities to play like all kids do—by pressing a button. Cleveland said the adaptations are based on basic circuit knowledge: putting an aux plug in parallel to the button on the toy. The aux plug allows for a bigger, more accessible button to be attached to the toy that is activated by children with their fist, elbows, head, knees, or feet.



*(From left to right) Jerika Cleveland, Henry Wolf, Armin Ekic*

With this modification, the expensive buttons, which cost US \$60 to US \$100 each, can be removed from one toy and used with multiple toys, saving families money by being able to use fewer buttons.

The Chapter also adapted the toys for free (with the audio jack, heat shrink, and wiring costing about US \$2.50). The price of a single adapted toy can increase by US \$30 to US \$50 when purchased through companies.




*These toys were modified as part of the program*

"The Toy-Adaptation is becoming the highlight of HKN- Gamma Tau Chapter's fall semester," said Chapter President Jerika Cleveland, a Ph.D. student, who led the Chapter's efforts. "Seeing electrical and computer engineering students, who have finals to study for and projects to finish, come together to adapt toys brings a bit of cheer to the group and department. Walking a dinosaur down the hallways always gets a laugh out of fellow students."

Disability services and teachers who work with disabled children are grateful for the adaptations, Cleveland said: "Making the toys activate with the accessible buttons allows the children to learn how to interact with the world. As the children get older, the big buttons will help the children interact with computers and assistant devices. This may provide independence and a voice to them as they grow up, so learning how to use the buttons early is important."

If you would like to learn more or start your own toy adaption program, contact [Jerika Cleveland](#).

To see one of the toys at work, go to <https://youtu.be/pl6YsqdH-08>. 



# Mu Beta Chapter's Kidzineers STEM Outreach Program

*Submitted by Heba Shaban, Faculty Advisor*

*Mu Beta Chapter, Arab Academy for Science, Technology & Maritime Transport (AASTMT)*

The Mu Beta Kidzineers program was recently launched by IEEE-HKN Mu Beta Chapter members as a STEM outreach program for pre-university students. The program aims to provide mentoring to pre-university students as well as educational activities and competitions. Our goal at the Mu Beta Kidzineers program is to give pre-university students the chance to learn, collaborate with their peers, and pursue their careers. Being a part of IEEE-HKN, we also aim to promote the goals of HKN, namely, scholarship, character and attitude.

To jump-start the program, a series of scientific facts was posted weekly to the program's social media pages, where the Chapter's media team works on unique designs for the posts to make them attractive to pre-university students.



*Mu Beta Chapter members holding the outstanding chapter plaque and key chapter recognition*

The Mu Beta Kidzineers program is now available on the [STEM portal](#) of IEEE's [TryEngineering.org](#) website. Through this portal, STEM best practices and programs are shared with IEEE's community of volunteers.

The Mu Beta Kidzineers program social media pages can found here @mubetakidzineers [f](#) [i](#) [t](#)

17 MS programs to  
choose from, plus 4 new  
100% online programs

Learn more:  
**[go.tufts.edu/engmasters](https://go.tufts.edu/engmasters)**  
PhD, certificate, and postbac programs also available

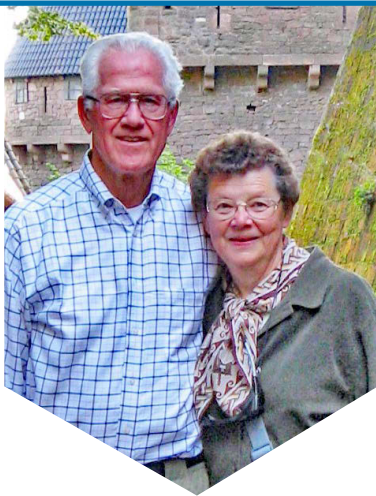
**Tufts**  
UNIVERSITY

School of  
Engineering

**EARN A MASTER'S  
IN ENGINEERING**

in as little as one year or at your own pace.

## Donor Profile



### Lyle Feisel, Ph.D.

IEEE Life Fellow  
Nu Chapter  
Iowa State University

Dr. Lyle Feisel, pictured with his wife, Dorothy, donates to IEEE-Eta Kappa Nu (IEEE-HKN) Fund, the IEEE Foundation Fund, the IEEE History Center Fund, and the IEEE Life Members Fund.


You can choose to directly [support IEEE-HKN](#) or any of the strategically identified IEEE initiatives that help meet the world's most pressing challenges and help us to realize the full potential of IEEE.

## Harnessing Strength in Numbers

As a member of the American Institute of Electrical Engineers (AIEE) and The Institute of Radio Engineers (IRE)—organizations which ultimately evolved into IEEE in 1963—IEEE Life Fellow Dr. Lyle Feisel has enjoyed the benefits of his IEEE affiliation for more than 60 years.

"The student branch gave us opportunities to socialize with faculty and other students and gain insight into the actual practice of engineering, and the networking and technical information I received were so helpful," said Dr. Feisel, who served on the HKN National Board from 2003 to 2006. "The camaraderie and friendships that developed over the years are some of my fondest memories of being an IEEE member."

Dr. Feisel attributes his decision to donate to such initiatives as the IEEE-Eta Kappa Nu ([IEEE-HKN](#)) Fund, the IEEE Foundation Fund, the IEEE History Center Fund, and the IEEE Life Members Fund, to "the recognition that there are many needs out there and that our contributions can help meet them," he said. "My wife and I have also included the IEEE Foundation in our estate plan because you can't take it with you, so why not have it used for something you believe in? The IEEE Foundation is a very efficient and effective charity that will make good use of any bequest."

"The critical function of the IEEE Foundation—or any charity—is that it lets you help accomplish a goal that you could never achieve by yourself," Dr. Feisel explained. "Acting alone, we could never put a girl through high school in Guatemala, teach a class in New Jersey about the history of engineering, illuminate a light bulb in Haiti, or take a kid for a ride on a replica sailing ship. By giving to the IEEE Foundation and other charities," he said, "we're able to help do all of those things." 

## Are You Eta Kappa Nu? Show Your Eta Kappa Nu!

If it's not on your card, it's not in your IEEE membership record. **Let us know!**

 800-406-2590  [www.hkn.org](http://www.hkn.org)  [info@hkn.org](mailto:info@hkn.org)



THE BRIDGE

Are you celebrating a milestone anniversary as an HKN member? Share your story and photos with the entire IEEE-HKN family. Submit a paragraph or two about your journey and photos of yourself participating in HKN activities or of your HKN memorabilia. Your submission will appear in a future issue of *THE BRIDGE* or in our Alumni Newsletter. [Email us](#) to learn more and to share your story.

## Congratulations, John McDonald, IEEE-HKN for 50 Years

John McDonald, P.E., Smart Grid Business Development Leader for GE's Grid Solutions business, is an exemplary IEEE-Eta Kappa Nu member who demonstrates how to pursue excellence in all areas. John has published 150 papers and articles, co-authored five books, has one US patent, and has held countless leadership positions in different organizations.


The quest for academic and professional excellence needs to be coupled with the pursuit for relationship excellence, he says. One way to pursue relationship excellence is by constantly looking for ways to give back. "We can always find the time to do what we want to do," he says. "No matter how busy I am, I will find time to help others succeed."

John is a dedicated volunteer with IEEE-HKN, serving on the Strategic Planning Committee. Through IEEE-HKN, he says he is able to inspire others and encourage them in their professional journey by being a role model who leads others by his actions, not just his words. In fact, he recently gave of his time again by offering a session on the "[12 Key Insights to Career Management](#)" at IEEE-HKN's Pathways to Industry program. You may watch it by [following this link](#).

He says he enjoys giving back to Eta Kappa Nu because of the reinforcement and confidence he received when being inducted as a student in 1971. As he thinks over his years in industry, he realized: "I've come to the point in my career where I've already had plenty of awards and recognition, I don't need that anymore. My greatest satisfaction is helping a young person be successful themselves, and when they achieve success, seeing how happy they are and knowing I had something to do with that. What really drives me today is to help other people."

John is an IEEE Foundation Director, and has served on the Board of Governors of the IEEE-SA (Standards Association). He is Past President of the IEEE Power & Energy Society (PES), the Past Chair of the IEEE PES Substations Committee, and the IEEE Division VII Past Director.

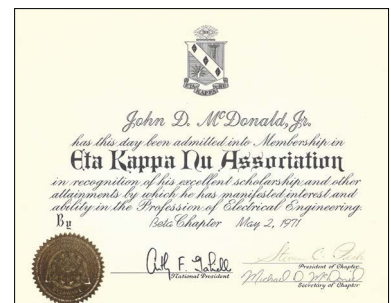
John, a Life Fellow of IEEE, was awarded the IEEE Millennium Medal, the IEEE Power & Energy Society Excellence in Power Distribution Engineering Award, the IEEE PES Substations Committee Distinguished Service Award, and the IEEE PES Meritorious Service Award.

Congratulations, John! We thank you for all you have given to the IEEE-HKN family. 



John McDonald,  
P.E.

Smart Grid Business  
Development Leader, GE  
Beta Chapter, 1971  
Purdue University





# Congratulations, 2019-2020 Outstanding Chapter Award Winners!


The IEEE-Eta Kappa Nu (IEEE-HKN) Board of Governors is excited to announce the Outstanding Chapter Award winners for the 2019-2020 academic year.

The 21 Chapters recognized represent the top 15 percent of the Chapters worldwide. The Outstanding Chapter Award (OCA) recognizes excellence in IEEE-HKN Chapters for their activities.

The award is based on the content and description of Chapter activities that are contained in the Annual Chapter Report, which summarizes the Chapter's activities from the previous academic year.

For the purposes of this award, emphasis is on service activities to the department, school, community and Chapter. Equally important is promoting the goals of IEEE-HKN by inducting as many eligible undergraduate students, graduate students and faculty in the IEEE designated technical fields of interest as possible and by participating in IEEE-HKN student Chapter projects.

Each recipient Chapter will be recognized at the 2021 [IEEE-HKN Graduation Celebration](#) scheduled for 2 p.m. (EDT) on 5 June. They also will receive an engraved plaque.

Congratulations to the honorees and thank you all for your service to IEEE-HKN, your university and your community. We hope you will join us at the celebration on 5 June. [Register here.](#) 



## The 2019-2020 Outstanding Chapter Award recipients are:

Alpha	University of Illinois at Urbana-Champaign
Beta	Purdue University
Beta Epsilon	University of Michigan, Ann Arbor
Beta Eta	North Carolina State University
Beta Theta	Massachusetts Institute of Technology
Delta Omega	University of Hawaii at Manoa
Epsilon Delta	Tufts University
Epsilon Eta	Rose-Hulman Institute of Technology
Epsilon Omicron	University of Delaware
Iota Gamma	University of California, Los Angeles
Kappa Psi	University of California, San Diego
Lambda Tau	University of Puerto Rico at Mayaguez
Mu	University of California, Berkeley
Mu Alpha	UCSI University Kuala Lumpur
Mu Beta	Arab Academy for Science & Technology - Alexandria
Mu Nu	Politecnico Di Torino
Mu Rho	Valparaiso University
Mu Tau	Waseda University
Nu	Iowa State University
Sigma	Carnegie-Mellon University
Zeta Delta	University of Texas at El Paso

## ECEDHA and IEEE-HKN Partner for Student Success

Few organizations have the synergy and alignment like IEEE-Eta Kappa Nu and The Electrical and Computer Engineering Department Heads Association (ECEDHA). The challenges of preparing, engaging, inspiring, and involving students is best met when Department Heads and HKN Chapters work together.

That is why the two organizations have a long history of working together to meet the needs of our Chapters.

ECEDHA is the premier academic association of its kind encompassing all major electrical engineering, computer engineering, and related programs at universities across North America. ECEDHA's mission is to foster advances in the disciplines of electrical and computer engineering, facilitate interaction and exchange of ideas among its members, and improve communication with the profession, industry, government, and other communities of interest.

**In just the last six months alone, IEEE-HKN and ECEDHA have collaborated on three programs:**


- ECEDHA and HKN: Partnering for Student Success, a one-hour learning session held during the 2020 HKN Experience last November. It is available to [watch on demand](#).
- Lessons Learned: Student Insights on Fall 2020, in which two IEEE-HKN students participated in this

panel as part of ECEDHA's Educators Summit in December of 2020. You may view the panel [on demand](#).

- ECEDHA + IEEE-HKN = Recipe for Success, a town hall event that presented several case studies of successful partnerships, highlighted the service component of HKN, and how Department Heads can achieve their objectives for student success and outreach in their campus communities. The three Town Hall sessions are available on the [IEEE-HKN YouTube channel](#):
- **Session 1 IEEE-HKN: Not Just Another Student Organization**
- **Session 2 IEEE-HKN Impact: How Your Department Will Benefit from Your HKN Chapter**
- **Session 3 Enhancing Student Life & Peer-to-Peer Community**



The [ECEDHA Summit Series](#) presents virtual programs organized by ECEDHA leadership and offered to ECE educators on a quarterly basis. The summits provide a forum for peers to gather, learn, and share best practices addressing common challenges. Each two-day summit focuses on a subject area of particular interest to the ECE community, such as the Educators Summit in December.

If you would like to learn more about ECEDHA, including information on the next Summit Series, visit [www.ecedha.org](http://www.ecedha.org). You may also contact Megan Bekolay, Program Director, ECEDHA, at [mbekolay@ecedha.org](mailto:mbekolay@ecedha.org). 

## 2021 Outstanding Student Award Applications Due 30 June

The Alton B. Zerby and Carl T. Koerner Outstanding Student Award recognizes outstanding scholastic excellence and high moral character, coupled with demonstrated exemplary service to classmates, university, community, and country.

Each Chapter may nominate one member for this award each year.

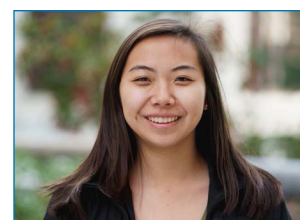
**Who will you Chapter nominate?**

**Applications are due 30 June 2021**

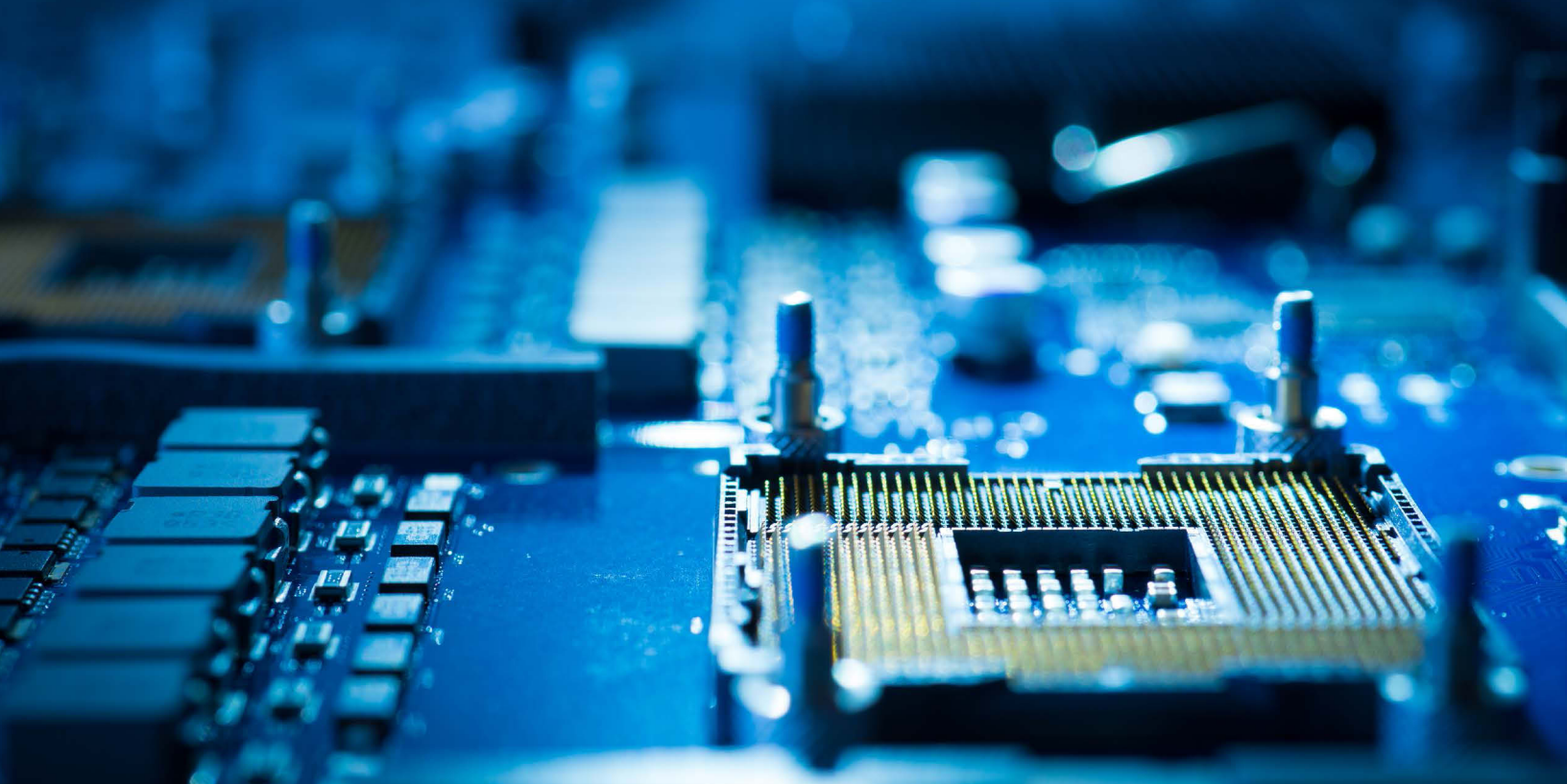
**LEARN MORE**



Alvaro Sahagan,  
2020  
Award  
Winner



Olivia Hsu,  
2019  
Award  
Winner



# Modeling of organic semiconductor conduction parameters with reference to inorganic semiconductors

By Abdelhalim Zekry, W. Abdelaziz

The authors are with the Department of Electronics and Electrical Communications, Faculty of Engineering, Ain Shams University, Cairo, Egypt (e-mail: [aaazekry@hotmail.com](mailto:aaazekry@hotmail.com); [eng.walaa2005@gmail.com](mailto:eng.walaa2005@gmail.com)).

## Abstract

This paper shows how the electronic properties of organic semiconductors can be described in the same way as the inorganic semiconductors. This is required for exploiting the existing electron device simulators in solving also the organic semiconductor devices. In addition such a description will make such important class of materials easier to understand.

## Introduction

Organic semiconductors can be broadly divided into polymers and small-molecule materials. There are notable differences from a chemical point of view between these two classes, affecting their technological performance. Polymeric macromolecules are composed by the repetition of a fundamental unit, called the monomer, and are soluble in organic solvents. Accordingly, they can be processed in liquid form. Small-molecule materials, termed also molecular materials, can be further divided

into two subgroups, the pigments, which are not soluble in organic solvents, and dyes, which are soluble. As a result of their chemical properties, polymers can be solution processed whereas small-molecule materials must be in general thermally evaporated.

Studying the properties of organic semiconductors helps in utilizing them efficiently to innovate new electronic devices. If these properties are referenced to inorganic semiconductors [1], then they can be considered as their extension. As there is a wealth of computer aided analysis and design tools for the inorganic semiconductors, then one can apply them also for the modeling and simulation of the organic semiconductors with the proper modifications to account for the properties of the organic materials. So, in this paper the organic semiconductors are modeled as their inorganic counterparts. The model similarities and differences are pointed out.



## Modeling of organic semiconductor conduction parameters with reference to inorganic semiconductors

It is found that the semiconductor parameters could be the same in both classes of semiconductors but their mathematical formulations and range of values are different.

The semiconductor properties and parameters treated in this paper are:

- The organic semiconductor atomic arrangement
- Arrangements of molecules in the organic materials
- The energy band structure of the organic semiconductor
- Carriers in equilibrium in the organic semiconductor
- The doping of the organic semiconductors
- Current conduction in organic semiconductors
- Recombination of mobile charge carriers in organic semiconductors
- The semiconductor equations

### The organic semiconductor atomic arrangements

The arrangements of the atoms inside the material control its physical properties including the electronic and optical properties. The atomic arrangements depend on the chemical bonding between the constituting elements of the material and their electronic configuration.

The organic semiconductors are compounds having atomic arrangement patterns as the organic materials. The main feature of such a structure is that it is a molecular one with strong covalent bonds inside the molecules and weak inter molecular bonding mostly by van der Waals forces. So, the organic semiconductors are composed from organic molecules arranged randomly or regularly or in a mixed fashion.

Figure 1 shows the atomic configuration of typical organic semiconductor molecules. One sees that thanks to the presence of the carbon atoms in the molecules of the organic semiconductors, the bond in the molecule core is covalent like that of metallic silicon semiconductor. It is also noticed that all bonds in the molecules are saturated and therefore the intermolecular bonding will be of van der Waals dipolar bonding which is weak.

Therefore, we find that these materials are highly ductile and classified mechanically as plastic materials. So, they have different mechanical properties from the metallic semiconductors such as silicon which is hard and stiff.

There are thousands of possible variations in these structures, including substitution of some carbons for

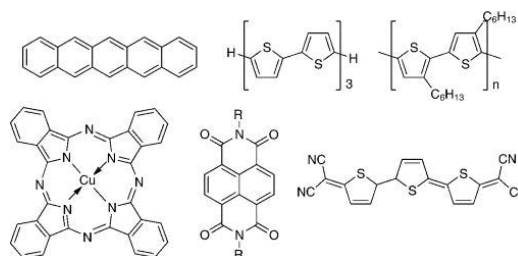


Figure 1: Typical molecular structures leading to OSC materials. Top, from left: pentacene,  $\alpha$ -sexithiophene ( $\alpha$ -6 T), poly(3-hexylthiophene) or P3HT. Bottom, from left: copper phthalocyanine, naphthalenetetracarboxylic diimide (NTCDI), terthiophene tetracyanoquinodimethane. The first four are hole carriers, and the last two electron carriers.

heteroatoms and appending vast libraries of side chains that enable tuning of charge transport, processing conditions, and chemical interactions [2].

### Arrangements of molecules in the organic materials

As the organic materials are composed of organic molecules, then the geometrical arrangement of the molecules in the materials affects much its electronic and optical properties as they define the intermolecular interaction. This issue is similar to the formation of crystalline structures in inorganic semiconductors.

So, one can consider that the organic semiconductor is basically a fine-grained semiconductor with a molecule representing a grain. The charges can move easily inside the molecule as consequence of its extended valence structure, but at the molecule boundary there will be potential barriers that impede the motion of the charge carriers. So, it is clear that the transport of charges between the molecules is the limiting factor for this movement. This is similar to the transport across the grain boundary in metallic semiconductors.

Many research efforts are spent to control the intermolecular interaction to ease the motion across the molecules of materials by controlling their molecular arrangements during the deposition process. The arrangement of the molecules ranges from regularly ordered molecules to randomly ordered molecules [3]. Figure 2 depicts some of these arrangements.

Progress in fabrication, particularly solution processing, and characterization of small-molecule and polymer organic semiconductors could enhance these materials and utilize them in industrial products such as organic

field effect transistors (OFETs) and light emitting diodes (OLEDs) playing an increasingly important role in modern technology. Further advantages of organic semiconductors compared to conventional silicon-based materials include mechanical flexibility, lightweight and easy and inexpensive solution process ability. Continuous refinement of design strategies and fabrication techniques allowed them to now routinely display impressive charge carrier mobilities of over  $1 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ , reaching as high as  $20\text{--}40 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$  in single crystals and even hundreds of  $\text{cm}^2 \text{ V}^{-1} \text{ s}^{-1}$  in ultrapure samples at low temperatures.

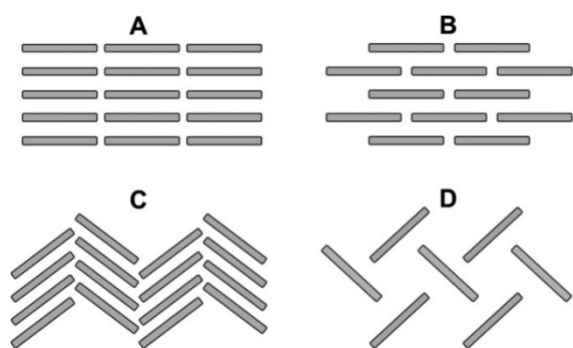


Figure 2: Typical aggregates and crystal packing motives of the  $\pi$ -conjugated cores: (A) lamellar  $\pi$ - $\pi$  stacking motifs with one-dimensional charge carrier channel, (B) brick-stone or brick-wall (also called  $\beta$ -sheet) arrangement with two-dimensional  $\pi$ - $\pi$  stacking; (C)  $\gamma$ -packing with slipped face-to-face  $\pi$ - $\pi$  stacking; (D) herringbone face-to-edge packing without face-to-face  $\pi$ - $\pi$  overlap.

### The energy band structure of the organic semiconductor

As the organic materials are composed of molecules weakly bound to each other therefore, the energy band structure will be that of the molecules with limited splitting of the energy levels to form narrow bands. The energy band structure was investigated using the density function theory. It is found that valence and conduction bands are formed with Gaussian distribution of the density of states around the conduction band edge  $E_c = E_L$ , the LUMO level and the valence band edge the HOMO level.  $E_v = E_H$ . The conduction band and the valence band have effective density of states  $N_c$  and  $N_v$ , respectively. This description of the energy band structure is similar to that of the inorganic semiconductors.

A typical density of state  $\text{DOS}(E)$  as a function of the energy  $E$  is shown in Figure 3 for an organic material and inorganic semiconductor for sake of comparison.

The DOS of the organic materials is Gaussian while that of the inorganic is a square root function of energy difference from the band edge.

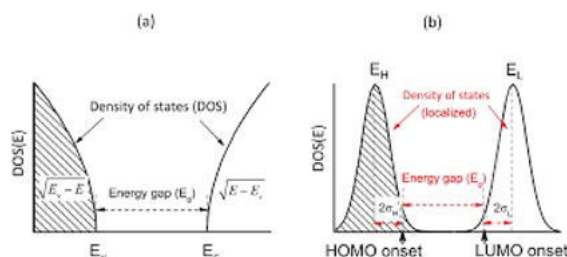


Figure 3: Density of states ( $\text{DOS}(E)$ ) as a function of the energy ( $E$ ) for metallic and organic semiconductors.

The effective density of state assumes that the density of states is located at the positions of  $E_c$  and  $E_v$  as well as  $E_L$  and  $E_H$ , respectively as depicted in the same figure. Finally, the energy level diagram of the organic semiconductor is shown in Figure 4, where  $\chi$  is the electron affinity,  $E_f$  is the Fermi-level,  $E_g$  is the band gap and  $\phi$  is the work function of the materials.

So, formally the energy band diagram of organic semiconductor is similar to that of inorganic semiconductor [4].

### Carriers in equilibrium in the organic semiconductor

#### The intrinsic concentration $n_i$

Generally, in any semiconductor there are two types of mobile charges: the electrons in the conduction band and the holes in the valence band. If the material is pure and intrinsic the source of the electrons and holes will be the thermal generation of electron hole pairs. The concentration of the electrons will be equal to that of the holes  $n_o = p_o = n_i$  according to the mass action law,  $n_o p_o = n_i^2$  [5]. The intrinsic concentration is given by;  $n_i^2 = N_c N_v \exp(-E_g/KT)$ , where  $K$  is the Boltzmann constant and  $T$  is the absolute temperature. This law is general and applicable for all semiconductors.

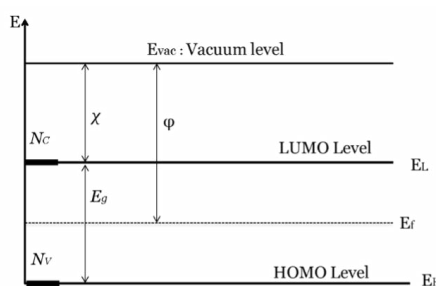


Figure 4: The energy level diagram of the organic semiconductor.

## Modeling of organic semiconductor conduction parameters with reference to inorganic semiconductors

Organic semiconductor materials have relatively higher energy gaps compared to the most common semiconductor metallic material, e.g. silicon (Si). The effective density of states according to the data in the literature are not much different from those of silicon, therefore, the intrinsic concentration of the organic materials is very small. Accordingly, organic materials approach the insulators rather than the semiconductors. In this sense, practically in their intrinsic state they behave as an insulator.

Regarding the purity of the materials, metallic semiconductor is produced with high purity but the organic semiconductors are produced with less purity and they contain impurities leading to make them either p-type or n-type conducting.

Once doped either intentionally or unintentionally one can define for them a Fermi level as in the metallic material. Otherwise, one describes them as insulators, in the sense that their energy levels are aligned to the vacuum level. If the material is doped, the energy levels through a system of materials are aligned to Fermi level at thermal equilibrium.

### The doping of the organic semiconductors

The doping of the metallic semiconductors is by atomic substitution while in the organic material it is by adding doping atoms or doping molecules. The doping by atoms is inferior than doping by molecules as the doping by atoms results in unstable materials [6]. The organic materials can then be doped by adding molecules where one gets n-type and p-type conduction. In case of doped organic semiconductor one can define a Fermi level for the material  $E_f$  such that one can express the electron concentration by a relation similar to that of the inorganic materials such that the electron concentration  $n$  can be expressed as in (1)a :

$$n = N_C \exp\left(\frac{-(E_C - E_f)}{KT}\right) \quad (1) \text{ a}$$

The same holds for the p-type organic semiconductor such that the hole concentration  $p$  can be written as:

$$p = N_V \exp\left(\frac{-(E_f - E_V)}{KT}\right) \quad (1) \text{ b}$$

In case of n-type the donor molecule gives an electron to the host molecules and it becomes a positive ion which is considered immobile similar to the doping in the metallic semiconductor. There is also an ionization

potential of the doping molecules where the doping level is lying under the LUMO level by ionization energy  $E_{id} = E_L - E_D$ .

In a doped material, to determine the Fermi level one uses the mass action law and the neutrality equation as in the metallic semiconductors such that the following relations hold:

The neutrality equation  $n = N_{d+} + p$ , Where  $N_{d+}$  is concentration of the ionized donor molecules.

The mass action law  $np = ni^2$ , the Fermi Dirac distribution function  $N_{d+} = N_d f(E_d)$ ,

Where;

$$f(E_d) = \left( \frac{1}{1 + \exp((E_d - E_f)/KT)} \right) \quad (2)$$

Similar equations hold for the acceptor molecules.

### Current conduction in organic semiconductors

The current conduction mechanisms in metallic semiconductors are also applicable in the organic semiconductors. The common current mechanisms in both types of semiconductors are the drift and the diffusion currents. The mobile charge carriers can drift under the influence of the applied electric field and can also diffuse under the concentration gradients. The drift current  $J_{drift}$  can be expressed by the known relation as in (3):

Where  $E$  is the intensity of the electric field,  $q$  is

$$J_{drift} = q(n \mu_n + p \mu_p) E \quad (3)$$

the electronic charge,  $\mu_n$  and  $\mu_p$  are the mobility of electrons and holes, respectively and  $n$  and  $p$  are the electron concentration and the hole concentration, respectively.

The mobility  $\mu$  is different from that of the metallic semiconductors because of the nature of the organic semiconductors. Here the electrons hop across potential barriers from a molecule to its neighboring one. The depth of the potential barriers is randomly distributed around certain average value. It results that the mobility will be dependent on the applied electric field and the temperature in an activated transport process. Specifically, the mobility increases by increasing the electric field and temperature [7].



The other current that can exist in the organic material is the diffusion current when concentration gradients of electrons and holes can be formed. The diffusion current  $J_{diff}$  has the well-known expression:

$$J_{diff} = -qD_p \frac{dp}{dx} + qD_n \frac{dn}{dx} \quad (4)$$

Where  $D_p$  and  $D_n$  are the diffusion constants of the holes and electrons, respectively. The concentration gradients  $dp/dx$  and  $dn/dx$  are of holes and electrons, respectively.

The diffusion coefficient  $D$  is related to the mobility  $\mu$  by the Einstein relation:

$$D = V_t \mu \quad (5)$$

Where  $V_t$  is the thermal voltage.

There is also the space charge limited current SCLC when the electric conduction is affected by single type charges either electrons or holes.

The SCLC will be treated in detail when dealing with the conduction in metal organic semiconductor diodes. The space charge limited current prevails when the conduction is unipolar in originally semi insulating materials with very low mobility.

This state is presented in the intrinsic organic materials injected by either electrons or holes from metallic electrodes. It is observed many times in such organic materials.

### Recombination of mobile charge carriers in organic semiconductors

Recombination is the disappearance of a mobile electron in a hole. This process leads to the loss of mobile charge carriers and thereby affects much the electrical characteristics of the semiconductor devices including solar cells and light emitting diodes.

The recombination mechanisms were studied intensively in metallic semiconductors [5] and to less extent in the organic semiconductors.

From the conceptual point of view, the recombination mechanisms occurring in the metallic semiconductor also occur in the organic semiconductors. These mechanisms can be classified into radiative and non-radiative types. Radiative recombination is a consequence of the direct fall of electrons from the conduction band to the valence band while the non-radiative one when the fall of the electrons occurs

through trap levels in the bandgap. These trap levels are called recombination centers. The most dominant non-radiative recombination mechanism is that of the Shockley-Read-Hall. It exists in all semiconductor materials.

Every recombination mechanism has its specific dependence on the hole and electron concentrations and its rate constants. For more details on such recombination mechanisms, please refer to the ref. [5].

There is a specific recombination mechanism which exists in the organic semiconductors. It is the Langevin which occurs as direct consequence of an electron and hole comes in the field of the other in a low field mobility materials. They get this chance when they meet while moving. Its recombination rate  $r_{lv}$  can be expressed by [8].

$$r_{lv} = \frac{q}{\epsilon} (\mu_n + \mu_p) pn \quad (6)$$

Where,  $\epsilon$  is the permittivity. It is found that this mechanism is applicable in case of the organic LEDs, while it must be reduced by an appreciable factor when applied to organic solar cells. Generally, the rate can be expressed by  $r_{lv} = k_r pn$ , where  $k_r$  is the recombination rate constant that can be determined experimentally.

A quantity which can be used to characterize semiconductor materials is the minority carrier lifetime  $\tau$  which is defined by:  $\tau = dn/U_n$  [5], where  $U_n$  is the excess recombination rate for the electrons and  $dn$  is the excess electron concentration.

### The semiconductor equations

The semiconductor equations [5] are also applicable for the organic semiconductor as they are of general formulation. These equations are the, the poison equation, the current equation, and the continuity equations.

These equations can be formulated as:

$$\text{Div}(D) = \rho \quad (7)$$

With  $\rho$  is the charge density and  $D$  is the electric displacement.

$$\rho = q(N_a^+ + p - N_a^- - n) \quad (8)$$

Where,  $N_a^+$  and  $N_a^-$  are the ionized donor and acceptor molecules concentrations. The current equations can be written in the form:

## Modeling of organic semiconductor conduction parameters with reference to inorganic semiconductors

$$J_p = q\mu_p pE - qD_p \frac{\partial p}{\partial x} \quad (9)$$

And

$$J_n = q\mu_n nE + qD_n \frac{\partial n}{\partial x} \quad (10)$$

The continuity equation for holes in one dimension can be written as:

$$\frac{\partial p}{\partial t} = -\frac{1}{q} \frac{\partial J_p}{\partial x} - \frac{p-p_0}{\tau_p} + g_e \quad (11)$$

Where  $p$  is the hole concentration,  $J_p$  is the hole current density,  $p_0$  is the hole concentration at thermal equilibrium,  $\tau_p$  is the hole lifetime and  $g_e$  is the external generation rate that may be affected by suitable incident photon flux.


A similar continuity equation can be written for electrons:

$$\frac{\partial n}{\partial t} = -\frac{1}{q} \frac{\partial J_n}{\partial x} - \frac{n-n_0}{\tau_n} + g_e \quad (12)$$

Where,  $J_n$  is the electron current density,  $\tau_n$  is the carrier lifetime of electrons  $n_0$  is the electron concentration at equilibrium. These equations can be formulated in three dimensional forms. One simply uses napla operator for time rate of change of the carriers and the gradient one uses the div operator.

### Conclusions

In this paper we showed clearly that one can assign the same material parameters to inorganic semiconductors as organic semiconductor materials. One can assign for them, an effective mass, a mobility, a diffusivity, an energy gap, a Fermi level, doping concentrations as well as same recombination mechanisms. The major differences are in the numerical values of these parameters. In addition, there may be additional recombination mechanisms because of the very low mobile carrier mobilities in organic materials.

The most important conclusion is that one can use the same simulators intended for the inorganic devices to the organic semiconductor devices. This will save tremendous efforts to develop new simulators for the organic semiconductor devices. 

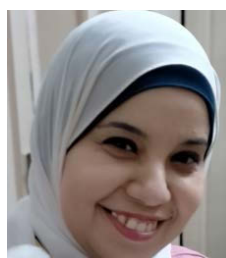
### REFERENCES

- [1] Zekry, A., Shaker, A., Salem, M., 2018. Chapter 1 - solar cells and arrays: principles, analysis, and design, *Advances in Renewable Energies and Power Technologies*, first ed., Yahyaoui.
- [2] Eric F.V. Scriven and Christopher A. Ramsden, "Chapter Five - Heterocyclic Building Blocks for Organic Semiconductors", *Advances in Heterocyclic Chemistry*, vol. 121, pp. 133 - 171, 2017.
- [3] Gryn'ova G, Lin KH, Corminboeuf C., "Read Between the Molecules: Computational Insights into Organic Semiconductors", *J. Am Chem. Soc.*, vol. 48, pp. 16370-16386, Nov. 2018.
- [4] Jin-Peng Yang et al, "Origin and role of gap states in organic semiconductor studied by UPS: as the nature of organic molecular crystal", *J. Phys. D: Appl. Phys.*, vol. 50, pp. 423002, Oct. 2017.
- [5] Abdelhalim zekry, "Electronic devices with physical insight", LAP LAMBERT Academic Publishing, 2019, 272 pages.
- [6] Lüssem, B., Riede, M. and Leo, K., "Doping of organic semiconductors", *Phys. Status Solidi A*, vol. 210, pp. 9-43, Dec. 2012.
- [7] Mandoc, Maria Magdalena, "Device physics of all-polymer solar cells", s.n., 134 p, 2009.
- [8] Holst, van der, J. J. M., Oost, van, F. W. A., Coehoorn, R., & Bobbert, P. A., "Electron-hole recombination in disordered organic semiconductors : validity of the Langevin formula", *Physical Review B*, vol. 23, pp. 235202-1/8, 2009.

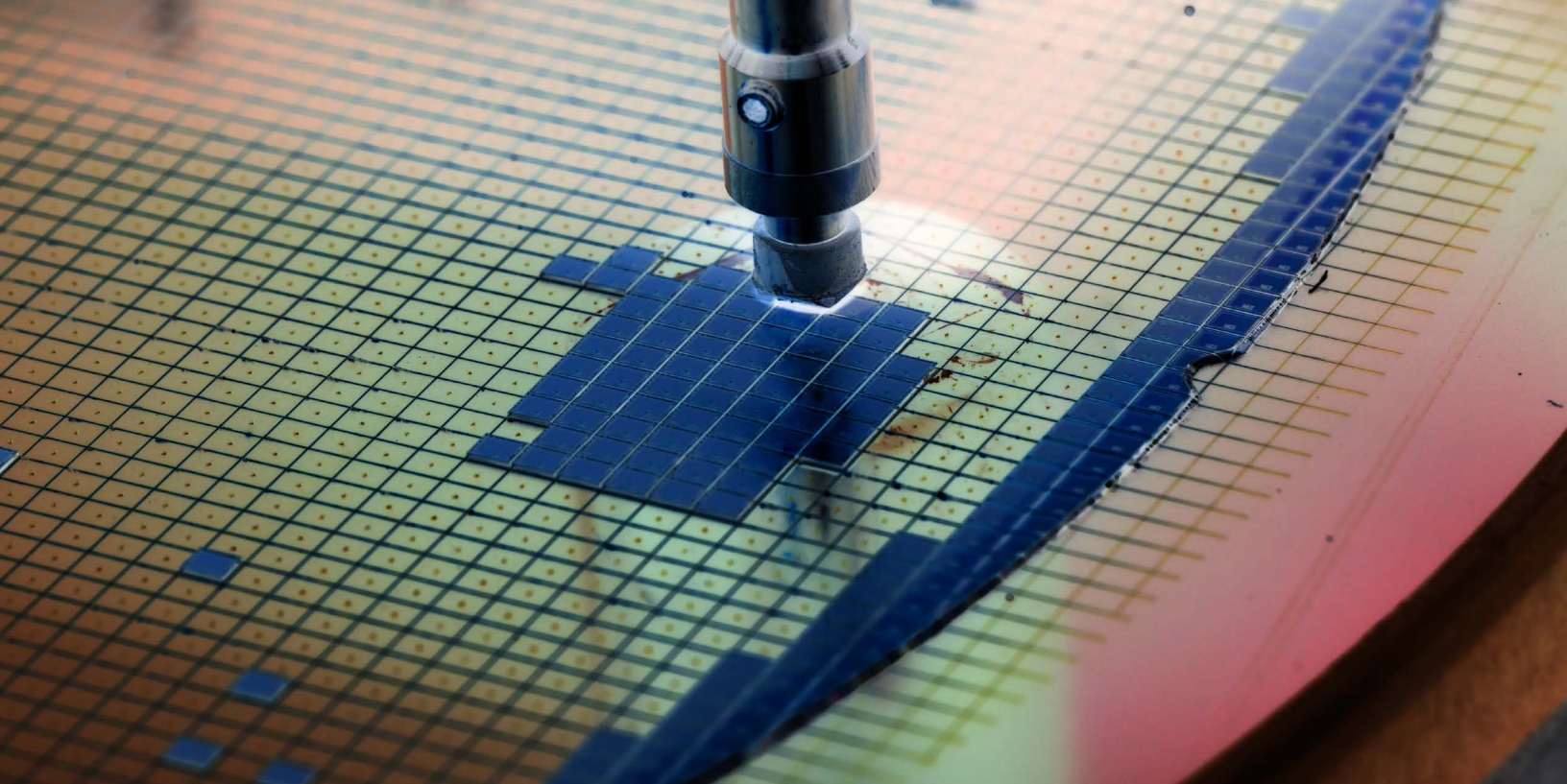


**Abdelhalim Zekry** is a professor of electronics at the Faculty of Engineering, Ain Shams University, Egypt. He has worked as a staff member at several universities. He has published more than 300 papers. He also has supervised more than 110 Master's theses and 40 Doctoral Dissertations.

Prof. Zekry focuses his research programs on the field of microelectronics and electronic applications including communications and photovoltaics. He has been awarded several prizes for his outstanding research and teaching performance.



**Walaa Abdelaziz** is a teaching assistant at the Modern Academy, Egypt. She graduated from Ain Shames University in 2005 and earned her Master's degree in 2012 from Cairo University. She focuses her research on renewable energy, especially solar cells.



# Modeling of organic semiconductor metallic contact and optoelectronic parameters with reference to inorganic semiconductors

By Abdelhalim Zekry, W. Abdelaziz

The authors are with the Department of Electronics and Electrical Communications, Faculty of Engineering, Ain Shams University, Cairo, Egypt (e-mail: [aaazekry@hotmail.com](mailto:aaazekry@hotmail.com); [eng.walaa2005@gmail.com](mailto:eng.walaa2005@gmail.com)).

## Abstract

This paper will show how the metal organic semiconductor junctions differ from those of the metal inorganic semiconductor contacts. In such contacts the current flow is normally space charge limited. In addition, optoelectronic properties are also modeled and the differences from the inorganic semiconductors are made clear. The idea of functional organic semiconductors is introduced and examples of such materials are given.

## Introduction

In order to access the organic semiconductor electrically one has to supply it with metallic electrodes. So, the metal organic semiconductor junction is a basic structure deserving detailed study.

Also, the optoelectronic properties of the organic semiconductors will be described as they have applications in optoelectronic devices.

Then specific functional organic semiconductor materials will be addressed to show how the organic semiconductor can perform specific functions in the electronic organic devices specially the solar cells.

So, the topics covered in this paper are:

- Conduction in metal organic semiconductor metal MOSM diodes.
- Optical properties.
- Functional organic semiconductors.



## Modeling organic semiconductor metallic contact and optoelectronic parameters with reference to inorganic semiconductors

### Conduction in Metal Organic Semiconductor Metal MOSM Diodes

The first challenge for determining the current of the MOSM Diode is the energy alignment at the metal organic semiconductor interface. When the semiconductor material is doped then one can define for it a Fermi level and accordingly the Fermi level will be constant at the interface similar to the metal- inorganic semiconductor.

In case of intrinsic organic semiconductor, it behaves as an insulator because of the relatively large bandgap and the amorphous nature of the material. In this case, the energy alignment will be according to the vacuum energy level. That is at equilibrium the energy levels align themselves to the vacuum level,  $E_{vac}$ . Such simplifying assumptions can facilitate the derivation of mathematical expressions for the currents.

Inspecting the literature concerned with the currents in the MOSM diodes with one charge type, it is found that the current can be either injection limited from the M-S contact or it can be space charge limited inside the semiconductor itself. The space charge limited current exists when it is much less than injection current. The injection current is limited by the height of the injection barrier at the contact which is more or less independent of the applied voltage except the image force barrier lowering and equal to the difference between the work function of the metal and the electron affinity of the organic semiconductor.

It is required to determine the factors limiting the current in the MOSM diode under the assumption of single charge type injection in the organic semiconductor. That is the metal can inject either electrons or holes in the organic semiconductor. Basically the current can be injection limited or space charge limited. In each case the I-V relationship of the diode is completely different.

Now let us describe the current of the MOSM diode when it is limited by the potential barrier between the metal and the organic semiconductor. Figure 1 shows the energy band diagram before contacting the diode layers and after contacting.

Assuming that the energy level alignment will be the vacuum level, then at the metal semiconductor contact of the cathode, a potential energy difference  $\phi_b$  between the metal and the organic semiconductor will be formed that can be expressed by the difference between the

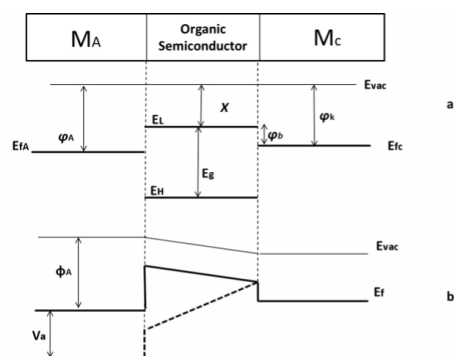


Figure 1: Energy level diagram a) before contacting MOSM diode and b) at equilibrium; the dotted line refers to energy level diagram at applied voltage  $V_a$ .

metal work function  $\phi_k$  and the electron affinity  $\chi$ , that is:

$$\phi_b = \phi_k - \chi \quad (1)$$

The current will be limited by the thermionic injection from the metal that can be expressed by the well known relation:

$$J = AT^2 e^{-\phi/kT} = J_0 e^{-\phi/kT} \quad (2)$$

With  $A = \frac{2\pi m q k^2}{h^3}$ , where  $\phi = \phi_b$ ,  $m$  is the effective mass and  $h$  is the Planck constant.

The origin of the space charge limitation is very low mobility of the organic semiconductors and the unipolar behavior in addition to the relatively low electric field. Accordingly, during their flow inside the material the charge carriers accumulate in it and build space charge that impedes the motion of the charges from the injector to the injecting contact to the collecting contact.

The space charge limited current is well known from the transport of electrons in vacuum and it is termed the three halves power law where the current is proportional to  $V^{3/2}$ , where  $V$  is the voltage across the diode. It also exists in the conduction by insulators, but with other forms.

For a 1D trap-free solid, the corresponding SCL current density is known as the Mott–Gurney (MG) law [1], given by:

$$J_{MG} = \frac{9}{8} \epsilon_0 \epsilon_r \mu_n \frac{V^2}{D^3} \quad (3)$$

Where  $\epsilon_r$  is the relative permittivity of the solid. If the solid has an exponentially distributed traps (in energy), it is known as the Mark–Helfrich (MH) law, or the trap-limited SCL current density  $J_{MH}$ ;

$$J_{MH} = N_C \mu_n^{1-l} \left[ \frac{\epsilon l}{N_t(l+1)} \right]^l \left( \frac{2l+1}{l+1} \right)^{l+1} \frac{V^{l+1}}{D^{2l+1}} \quad (4)$$

Here,  $N_c$  is the effective density of states corresponding to the energy at the bottom of the conduction band,  $N_t$  is the total trapped electron density, and  $I = T_t/T$  is the ratio of distributed traps to the free carriers.

The electron traps lie near the conduction band which is here the LUMO level while the hole traps lie near the valence band which is HOMO level. So, in principle there are hole traps and electron traps that affect electron mobility and hole mobility. There are also deep lying traps in the energy gap which can act as traps for both electrons and holes.

The deep lying traps can act as recombination centers, affecting the concentration of electrons and holes; while the electron traps affect the mobility of one charge type.

As for the conduction mechanisms, every one has its characteristic I-V relation, especially the voltage dependence and the thickness dependence of the active material in the diode,  $D$ . They can be used as indicators of the dominating mechanism.

Then by curve fitting of the current as a function of  $D$ , one can determine the physical parameters of the material. One can make additional measurements to verify some of the estimated parameters from the fitting such as the I-V measurements.

In case of doped organic semiconductor either unintentionally or intentionally the material will possess free carries and has a definitive Fermi level. In this case the material behaves as an ordinary semiconductor and builds Schottky contacts.

In this case the M-S contacts will follow the theory of Schottky junctions:

Where  $I_s$  is the reverse saturation current,  $\eta$  is the ideality

$$I = I_s \exp \left( \frac{V}{\eta V_T} - 1 \right) \quad (5)$$

factor. For the evidence for these findings please follow the Link in ref. [2].

Figure 2 shows a typical I-V curve of an organic semiconductor diode. It demonstrates the typical space charge limited current at the intermediate current density.

In summary, when one applies the voltage on the MOSM diode the current follows the drift current then turns to space charge limited current and then at high applied voltage the current saturates into the thermionic injection limited current. In case of doping the organic semiconductor the MOSM behaves as a conventional Schottky diode.

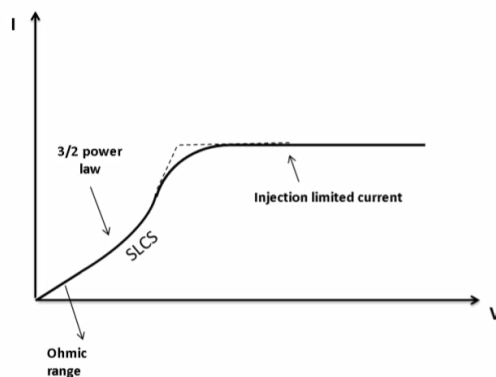


Figure 2: Typical I-V characteristic of an organic MOSM diode showing different mechanism of conduction.

### The optoelectronic properties of organic materials

We are interested in understanding the response of the semiconductor to light, i.e., the photoelectric effect. If a light beam is incident on a semiconductor material, part of the light energy will be reflected, a part will be absorbed inside the material after refraction and the remaining part will be transmitted. According to the energy conservation law:

$$I = R + A + T \quad (6)$$

Where  $I$  is the incident light energy, and  $R$ ,  $A$ , and  $T$ , respectively, are the portions reflected, absorbed, and transmitted.

Reflection occurs because of the change of the wave impedance,  $Z_w = \sqrt{\mu/\epsilon}$  at the surface of the material. The reflectance  $\rho$  is given by:

$$\rho = \left[ \frac{Z_w - Z_{wa}}{Z_w + Z_{wa}} \right]^2 \quad (7)$$

Where  $Z_{wa}$  is the wave impedance of the air,  $Z_{wa} = \sqrt{\mu_0/\epsilon_0}$ .  $\epsilon$  is the dielectric constant and  $\mu$  is the permeability. It is assumed that light is falling perpendicular to the surface. For a typical organic material with  $\epsilon$  equal around;  $4 \epsilon_0$ , and  $\mu = \mu_0$ ,  $\rho = 1/9$ , which is much less than that of silicon with  $\rho = 0.3$ , an appreciably larger than that of the organic materials. From this reflection point of view, the organic materials are performing better.

The absorption of the light energy is characterized by the absorption coefficient  $\alpha$ , where

$$I(x) = I(0)e^{-\alpha x} \quad (8)$$

## Modeling organic semiconductor metallic contact and optoelectronic parameters with reference to inorganic semiconductors

Which means that the incident light intensity  $I(0)$  at the surface of the material decays exponentially with the distance  $x$  from the surface. The intensity decays to  $(1/e)$  at  $x = 1/\alpha$ . Therefore, the inverse of  $\alpha$  is the average penetration depth of the light in the material, or may be better named the average absorption length. The absorption coefficient depends on the wavelength of the incident light. It is well established now that light is composed of energy quanta called photons. These photons interact with the electrons and atoms of the material. The photon energy is given by:

$$E_{ph} = hf \quad (9)$$

Where  $h$  is Planck's constant and  $f$  is the photon frequency. On the other side photons are wave packets having a wave length  $\lambda$ , and velocity  $C = 3 \times 10^8 \text{ m/s}$  such that  $C = hf$ . Therefore,  $E_{ph} = h(C/\lambda)$ . The photon energy is inversely proportional to the light wavelength. Now, we are in a position to understand how the light affects the material. Only valence electrons can absorb photons when they can acquire sufficient energy to overcome the energy gap of the material. More specifically, photons can excite an electron from the valence band, causing it to bind with a free hole and create an exciton (italicize the word). This process, denoted as photo-generation of excitons, is illustrated in Figure 3.

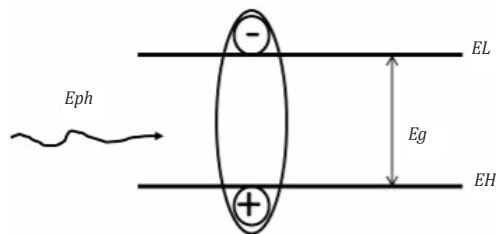


Figure 3: Photo-generation of excitons

From Figure 3, the required minimum photon energy for the photo-generation process  $E_{ph} \geq E_g$ . Energy rich photons, where e.g.,  $E_{ph} \sim 2 E_g$  cannot produce 2 excitons except with a very small probability as this process requires the collision of photons with two valence electrons simultaneously if it is a direct process.

The absorption coefficient  $\alpha$  is a function of the incident wavelength of the photons and it is a material property. Figure 4 shows typical shape of the absorption coefficient of different organic semiconductors as a function of the wavelength  $\lambda$ . The energy gap of the material is also given. It is clear from this figure that materials absorb light appreciably ( $\alpha > 100/\text{cm}$ ) only if  $E_{ph} \geq E_g$ . A second

important observation is that  $\alpha$  of the organic materials rises rapidly to maximum value then decreases again at short wavelengths. This absorption coefficient curve can be accounted for by the energy band structure of the organic materials discussed previously in section 3.

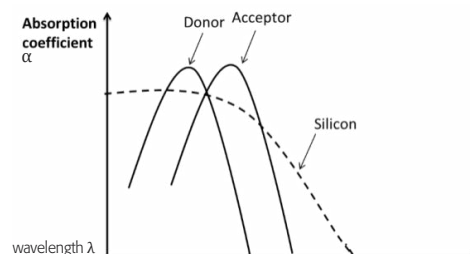


Figure 4: Typical shape of the absorption curves of the organic materials compared to silicon

For sake of comparison the absorption curve of silicon is plotted on the same graph for the organic materials. It is important to notice that the absorption coefficient of the organic material is much greater than that of silicon. The organic material has a band-pass absorption characteristic, in contrast to the high-pass absorption characteristic of the metallic material. The narrow band absorption of the organic materials limits it generated photocurrent. Therefore, this property could be considered inferior to the metallic semiconductors.

The longer-wave length photons with smaller  $\alpha$  need a thicker layer of the semiconductor to be absorbed otherwise they can be transmitted across the layer. Generally, the minimum semiconductor layer thickness to absorb light can be expressed by:

$$D_{\text{minimum}} \geq 2/\alpha \quad (10)$$

This simple relation is of a very critical importance for solar cell design. As the semiconductors are expensive one has to use the minimum quantity of them to perform the absorption function. In this concern, one needs thicker crystalline Si-layers as it has the lowest  $\alpha$ .

The required thickness to absorb the incident solar radiation by organic semiconductors is on the order of one hundred nanometers. Thin film structures are needed.

### Excitons in organic semiconductors

As described earlier, incident photons create bound electron-hole pairs known as excitons. These excitons have a specific lifetime called the exciton lifetime which is the time that an exciton lasts on the average before it disappears by recombination. Because excitons are neutral they move by diffusion inside the molecules



where they were created by light. So, the range of their motion is limited by the molecule sizes. It turns out that the diffusion length of the excitons is about few tens of nanometers in polycrystalline materials [3]. In contrast the photo-generated excitons in the metallic semiconductors are readily dissociated by the thermal energy as they are weakly bound thanks to the high dielectric screening.

In order to calculate the dissociation energy of the exciton, one can model the electron and its hole in the exciton as a modified hydrogen atom as shown in Figure 5. This model is similar to the hydrogen atom, except that the electron moves with an effective mass  $m_n$  in a medium with a relative dielectric constant  $\epsilon_r > 1$  instead of  $\epsilon_r = 1$  in a hydrogen atom. Then according to Bohr atomic model for the hydrogen atom, the required dissociation energy  $E_i$  of the exciton can be expressed by:

$$E_i = \frac{m_n E_H}{m_0 \epsilon_r^2} = \frac{13.6}{m_0 \epsilon_r^2} m_{ex} \text{ eV} \quad (11)$$

Where  $m_{ex}$  is the effective mass of exciton composed of electrons and holes. It is given by:

$$m_{ex} = m_n m_p / (m_n + m_p) \quad (12)$$

Where  $E_H$  is the energy required to ionize the hydrogen atom. For, metallic semiconductor as silicon,  $\epsilon_r = 12$ , so that the dissociation energy is of the order of 0.05 eV. While as for an organic semiconductor with a relative dielectric constant of 4 the dissociation energy amounts to 0.45 eV. When the effective mass is taken into consideration with the effective mass ratio is greater than one for the organic semiconductors, the binding energy or the exciton can be as high as one eV.

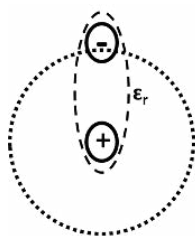


Figure 5: Hydrogen atom model of excitons where they move in a screening medium

This high binding energy of the excitons imparts a great problem for dissociating the excitons since to collect their electrons and holes they must be free. It is now clear that the good optical properties of the organic semiconductors of high absorption coefficient and low reflectance are offset by short lifetime, high binding energy of the excitons and narrow band absorption. It is so that the

small lifetime of the excitons can reduce the collection efficiency of the charge carriers and the high binding energy will be subtracted from the net available potential energy of the collected carriers in case of solar cell applications, in addition the narrow band absorption band.

### Functional organic semiconductors

To overcome the previously described functional shortage, some solutions have been devised by producing specific functional materials. In this section, these functional materials will be outlined.

#### The donor polymer materials

The donor polymer materials are organic semiconductors with long periodic molecules such as P3HT. They effectively absorb the incident solar radiation in their absorption range, producing excitons that diffuse in and across their long-chain molecules and across them. Their long molecules lead to exciton diffusion lengths that are limited to a few tens of nanometers, despite being relatively long.

#### The acceptor organic semiconductors

These materials have large affinity to the electrons such that when they brought in contact to the donor molecules, they will attract the electrons of the excitons formed in the donor materials. So, their LUMO level must lie under the LUMO of the donor molecules by an amount of energy greater than the dissociation energy of the excitons. In this way they will constitute an effective sink for the electrons of the excitons generated in the donor molecules. They must reflect the holes back to the donor absorber to suppress their recombination in the electron transport layer.

The concept of the acceptor material directly contacting the molecules of the donor molecules is a basic concept leading to the efficient dissociation of the excitons. Really it enabled the realization of efficient separation method for the generated electron hole pairs in the excitons. By transferring the electrons of the excitons to the acceptor molecules its chance for recombination becomes very small especially when one further transfers the electrons and holes far away from each other by collecting electric field. There are two classes of acceptor materials; the fullerene and the non-fullerene organic molecules. The fullerene is expensive, less stable in the environment and possesses weak optical absorption coefficient with narrow

## Modeling organic semiconductor metallic contact and optoelectronic parameters with reference to inorganic semiconductors

Table 1: Examples of organic materials

Organic materials	Type	$E_{Lumo}$ (eV)	$E_{Homo}$ (eV)	$\epsilon_r$	$\mu_n$ (cm <sup>2</sup> /V.s)	$\mu_p$ (cm <sup>2</sup> /V.s)
P3HT	Donor	3.2 [6]	5.2 [6]	3 [7]	—	$2.3 \times 10^{-4}$ [7]
PBDB-T	Donor	2.92 [8]	5.33 [8]	2.8 [9]	—	$3.06 \times 10^{-4}$ [10]
NCBDT	Non-fullerene acceptor	3.89 [8]	5.36 [8]	3.65 [8]	$1.58 \times 10^{-4}$ [11]	—
ITIC [9]	Non-fullerene acceptor	4.03	5.68	4.5	$6.4 \times 10^{-4}$	—
PCBM	Fullerene acceptor	4.2 [12]	6.1 [12]	3.9 [13]	$2 \times 10^{-7}$ [13]	—
PEDOT:PSS	HTL	3.1 [14]	5.1 [14]	3 [8]	—	$3.2 \times 10^{-4}$ [14]
PDINO	ETL	3.63 [15]	6.12 [15]	5 [8]	$3.15 \times 10^{-4}$ [16]	—
PFN-BR	ETL	2.37 [17]	5.65 [17]	5 [18]	$4.07 \times 10^{-7}$ [17]	—

bandwidth. The non-fullerene could be built to have an optical absorption curve complementing that of the donor material to render the whole donor acceptor complex a wideband optical absorber. This led to appreciable increase in the photo-conversion efficiency of solar cells [4, 5]. In this case the donor must accept holes and reject electrons back to perform a role similar to that of the acceptor facilitating the dissociation of the excitons generated in the acceptor material. Examples of the acceptor semiconductor are listed in Table 1.

### The transport layers


To produce a built-in field in the active zone of the donor acceptor region for further collection of the electrons and holes separated at the donor acceptor interface, one contacts the acceptor layer by an electron transport layer ETL and the donor layer by a hole transport layer HTL. Both layers must be chosen to be good conveyor of the electrons and holes to the respective metal electrode. So they have to have high conductivity and proper energy level diagram matching the donor and acceptor layers and making at the same time ohmic contacts to the metallic electrodes. Examples of the HTL and the ETL are given in the Table 1.

### Conclusions

This paper demonstrates that organic semiconductors can be described by the same phenomenological parameters as inorganic semiconductors [19], albeit with different mathematical expressions and ranges of values. With slight-to-moderate modifications, simulators for inorganic devices can be used to simulate organic devices.

### Notable points about organic semiconductors include the following:

- They are molecular in nature, with short-term order; in contrast to inorganic materials, which can have long-term order in crystalline form.
- They have relatively small mobilities, because of their amorphous nature.
- Despite being narrow-band absorbers of light, they have high absorption coefficients.
- Therefore, they need thin layers to absorb the incident light in their absorption band.
- Their dielectric constant is low, leading to excitons with high binding energy. This reduces collection efficiency of the charge carriers, which in turn reduces the net available energy of the solar cell.
- This problem has been solved through the use of donor and acceptor polymer materials.

In conclusion, despite some shortcomings, organic materials can be skillfully utilized to create electronic devices with unique properties. The road to widespread use of these materials in the electronic industry is long, but shows great promise. 

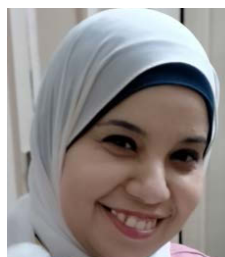
## REFERENCES

- [1] Zhu, Y. B. and Ang, L. K., "Analytical re-derivation of space charge limited current in solids using capacitor model", *Journal of Applied Physics*, vol. 110, pp. 094514, Oct. 2011.
- [2] Ishii, H., Hayashi, N., Ito, E., Washizu, Y., Sugi, K., Kimura, Y., Niwano, M., Ouchi, O. and Seki, K., "Kelvin Probe Study of Band Bending at Organic Semiconductor/Metal Interfaces: Examination of Fermi Level Alignment", *phys. stat. sol. (a)*, vol. 201, pp. 1075-1094, May 2004.
- [3] Mikhnenko, Oleksandr V. and Blom, Paul W. M. and Nguyen, Thuc-Quyen, "Exciton diffusion in organic semiconductors", *Energy Environ. Sci.*, vol. 8, pp. 1867-1888, May 2015.
- [4] Eftaiha, Ala'a F. and Sun, Jon-Paul and Hill, Ian G. and Welch, Gregory C., "Recent advances of non-fullerene small molecular acceptors for solution processed bulk heterojunction solar cells", *J. Mater. Chem. A*, vol. 2, pp. 1201-1213, Oct. 2014.
- [5] Jun Yuan, Yunqiang Zhang, Liuyang Zhou, Guichuan Zhang, Hin-Lap Yip, Tsz-Ki Lau, Xinhui Lu, Can Zhu, Hongjian Peng, Paul A. Johnson, Mario Leclerc, Yong Cao, Jacek Ulanski, Yongfang Li, Yingping Zou, "Single-Junction Organic Solar Cell with over 15% Efficiency Using Fused-Ring Acceptor with Electron-Deficient Core", *Joule*, Vol. 3, pp. 1140-1151, April 2019.
- [6] Petr P. Khlyabich, Beate Burkhart, Andrey E. Rudenko, Barry C. Thompson, "Optimization and simplification of polymer-fullerene solar cells through polymer and active layer design", *Polymer*, Vol. 54, pp. 5267-5298, Sept. 2013.
- [7] Si Chen, "Dielectric constant measurement of P3HT, polystyrene, and polyethylene", Master's Thesis / Essay, Chemistry, 2017.
- [8] W. Abdelaziz, A. Zekry, A. Shaker, M. Abouelatta, Numerical study of organic graded bulk heterojunction solar cell using SCAPS simulation, *solar energy*, Vol. 211, pp. 375-382, Nov. 2020.
- [9] Xi Liu, Boming Xie, Chunhui Duan, Zhaojing Wang, Baobing Fan, Kai Zhang, Baojun Lin, J. Fallon, M. Colberts, Wei Ma, A. Rene, J. Janssen, Fei Huang, Yong Cao, A high dielectric constant non-fullerene acceptor for efficient bulk-heterojunction organic solar cells, *J. Mater. Chem.*, Vol. 6, pp. 395-403, 2018.
- [10] Wang, Pang and Wang, Hui and Jeong, Mingyu and Lee, Sang Myeon and Du, Baocai and Mao, Yuchao and Ye, Fanghao and Zhang, Huijun and Li, Donghui and Liu, Dan and Yang, Changduk and Wang, Tao, "Dopant-free polymeric hole transport materials for efficient CsPbI<sub>2</sub>Br perovskite cells with a fill factor exceeding 84%", *J. Mater. Chem. C*, vol. 8, pp. 8507-8514, 2020.
- [11] Kan, Bin and Zhang, Jiangbin and Liu, Feng and Wan, Xiangjian and Li, Chenxi and Ke, Xin and Wang, Yunchuang and Feng, Huanran and Zhang, Yamin and Long, Guankui and Friend, Richard H. and Bakulin, Artem A. and Chen, Yongsheng, "Fine-Tuning the Energy Levels of a Nonfullerene Small-Molecule Acceptor to Achieve a High Short-Circuit Current and a Power Conversion Efficiency over 12% in Organic Solar Cells", *Advanced Materials*, Vol. 30, PP. 1704904, Dec. 2017.
- [12] Lee, E.J.; Choi, M.H., Moon, D.K., "Enhanced Photovoltaic Properties of Bulk Heterojunction Organic Photovoltaic Devices by an Addition of a Low Band Gap Conjugated Polymer", *Materials*, Vol. 9, PP. 996, Nov. 2016.
- [13] Elizabeth von Hauff, Vladimir Dyakonov, Jürgen Parisi, "Study of field effect mobility in PCBM films and P3HT:PCBM blends", *Solar Energy Materials and Solar Cells*, Vol. 87, pp. 149-156, May 2005.
- [14] Hia-Chih Chang, Jih-Hao Tao, Che-En Tsai, Yen-Ju Cheng, and Chain-Shu Hsu, "Cross-linked Triarylamine-Based Hole-Transporting Layer for Solution-Processed PEDOT:PSS-Free Inverted Perovskite Solar Cells", *ACS Applied Materials & Interfaces*, Vol. 25, pp. 21466-21471, 2018.
- [15] Yao, J., Qiu, B., Zhang, ZG. et al., "Cathode engineering with perylene-diimide interlayer enabling over 17% efficiency single-junction organic solar cells", *Nat Commun.*, Vol. 11, pp. 2726, June 2020.
- [16] Chen, Youchun and Wang, Shan and Xue, Lingwei and Zhang, Zhiguo and Li, Haolong and Wu, Lixin and Wang, Yue and Li, Fenghong and Zhang, Fengling and Li, Yongfang, "Insights into the working mechanism of cathode interlayers in polymer solar cells via [(C<sub>8</sub>H<sub>17</sub>)<sub>4</sub>N]<sub>4</sub>[SiW<sub>12</sub>O<sub>40</sub>]", *J. Mater. Chem. A*, Vol. 4, pp. 19189-19196, 2016.
- [17] Liu, Xiang and Chen, Zhiming and Xu, Rongguo and Zhang, Ruiwen and Hu, Zhicheng and Huang, Fei and Cao, Yong, "Finely Tuned Composition in Conjugated Polyelectrolytes for Interfacial Engineering of Efficient Polymer Solar Cells", *Small Methods*, Vol. 2, pp. 1700407, March 2018.
- [18] W. Abdelaziz, A. Shaker, M. Abouelatta, A. Zekry, "Possible efficiency boosting of non-fullerene acceptor solar cell using device simulation", *Optical Materials*, Vol. 91, pp. 239-245, 2019.
- [19] Zekry, A., Shaker, A., Salem, M., 2048. Chapter 1 - solar cells and arrays: principles, analysis, and design, *Advances in Renewable Energies and Power Technologies*, first ed., Yahyaoui.



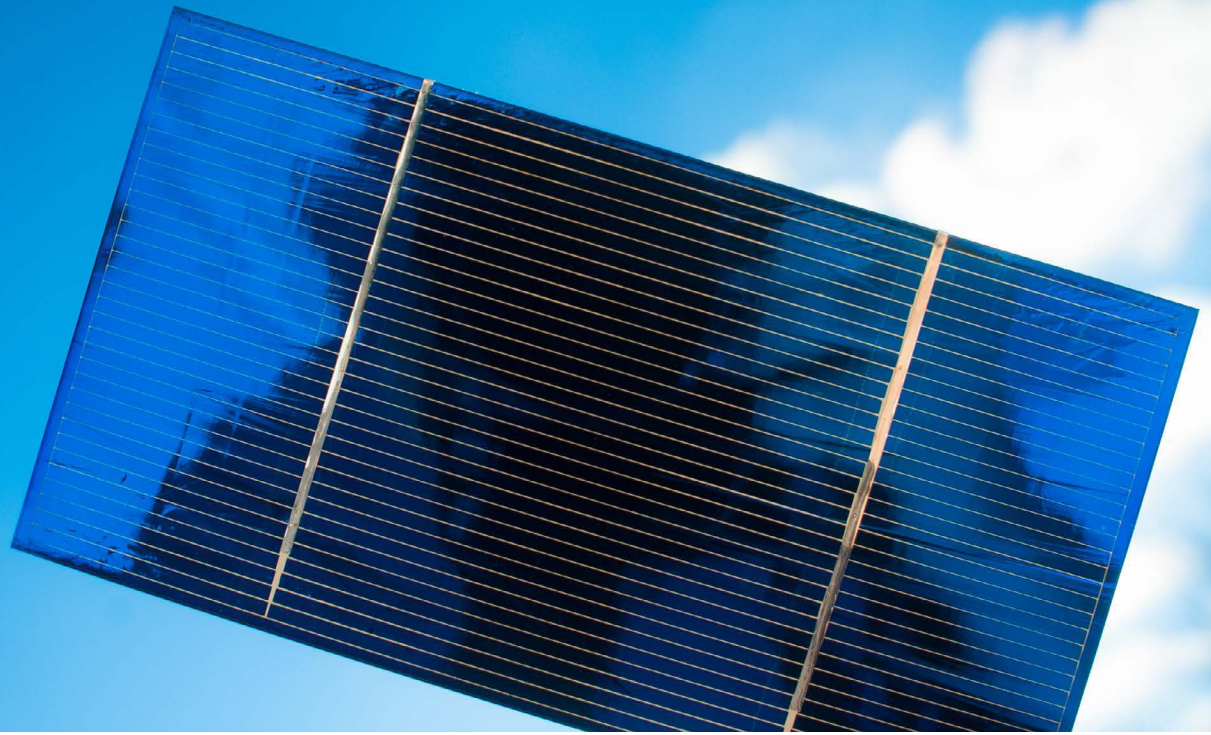
**Abdelhalim Zekry** is a professor of electronics at Faculty of Engineering, Ain Shams University, Egypt. He has worked as a staff member at several universities. He has published more than 300 papers. He also has supervised more than 110 Master's theses and 40 Doctoral Dissertations. Prof. Zekry focuses his research

programs on the field of microelectronics and electronic applications including communications and photovoltaics. He has been awarded several prizes for his outstanding research and teaching performance.



**Walaa Abdelaziz** is a teaching assistant at the Modern Academy, Egypt. She graduated from Ain Shames University in 2005 and earned her Master's degree in 2012 from Cairo University. She focuses her research on renewable energy, especially solar cells.





# A Review of Schottky Junction Solar Cells

By Amirhossein Ghods <sup>1</sup>, Chuanle Zhou <sup>1</sup>, and Ian T. Ferguson <sup>1,2</sup>

This paper reviews recent advances in development of high efficiency single and multi-layer  $p$ - $n$  junction and Schottky junction solar cells. The barrier formed at the interface of a thin conducting film, with a relatively high work function, and a semiconductor layer, leads to formation of a depletion region. The electric field at the depletion region results in separation of photo-generated charge carriers and a current flow towards the terminals of the solar cell. The simple and cost-effective fabrication process for metal-semiconductor Schottky solar cells make them suitable for use in large-scale photovoltaic devices, and potentially for commercial applications. However, the performance of these devices can be degraded due to a high leakage current and shunt conductance across the metal-semiconductor, which notably reduces their built-in voltage and ultimately their efficiency in comparison to traditional  $p$ - $n$  junction solar cells. The remainder of this paper presents the recent advances in improving the performance of Schottky junction solar cells are reviewed.

## I. A Roadmap to Address Global Warming

Renewable energy sources have always received much attention due to their “green” nature, in which they can generate electrical or mechanical power without emitting greenhouse gases. Moreover, the reduction in natural fossil fuel resources has increased the necessity for finding new alternatives to the traditional non-renewable energy sources. Based on the estimates from U.S. Energy Information Administration (EIA), as of 2019, about 11% of the United States and 26% of the global energy consumption is being supplied by the renewable sources [2].

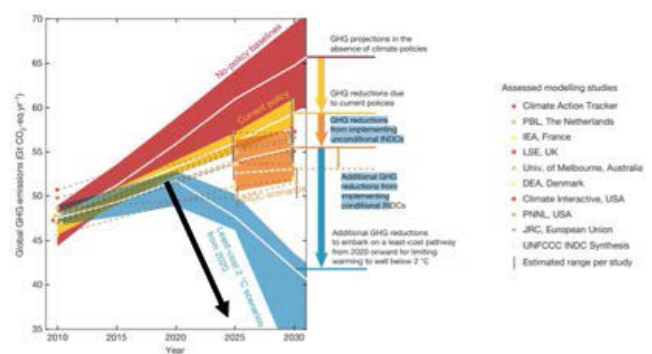


Figure 1. Efforts needed by different international entities to reduce the total greenhouse gas (GHG) emission in the next decade, in order to limit the rise of global temperature below 2°C [1].

Solar energy sources occupy about 6% of the total energy from renewable sources. The availability, accessibility, and low price of solar energy as compared to other renewables has led to increasing demand. The use of solar energy is growing across the globe, in both small-scale research and development applications and large-scale manufacturing processes. Examples of successful use of solar energy include the Tesla solar roof, portable solar chargers, and off-grid solar-powered manned and unmanned vehicles. Solar energy has proven to be an effective means of supplying electricity to remote and developing areas underserved by traditional power grids.

## II. Current State of Solar Cells

Increased use of solar energy to meet the world's energy demands has led to large investments and research in this area during the last few decades. However, the greatest two challenges have been to (1) increase the power conversion efficiency (PCE) of the solar cells, while (2) reducing their cost for large-scale fabrication [3]. In order to increase the maximum power conversion efficiency in solar cells, most research has been on the optimization of the solar cell structure and development of new semiconductor materials that can be used in a solar cell that can provide a higher efficiency. The level of photon absorption and the solar cell's power conversion efficiency is determined depending on the semiconductor's bandgap. In 1961, physicists William Shockley and Hans Joachim Queisser calculated the maximum theoretical power conversion efficiency of solar cells achievable from a simple p-n junction structure [4].

As can be seen in Figure 2.a, a maximum theoretical PCE of around 32% is calculated for solar cells made using semiconductor with bandgap energy around 1.1 eV, under typical solar illumination condition of AM1.5, equivalent to 100 mW/cm<sup>2</sup>. It should be noted that only 32% of solar energy is converted into electrical power and the rest is either not absorbed (below bandgap photons), thermally wasted due to relaxation of hot photons with energy higher than the bandgap, reflected from the top surface of the solar cells, or non-radiatively recombined, resulting into huge losses in power conversion efficiency of the solar cell, Figure 2.b.

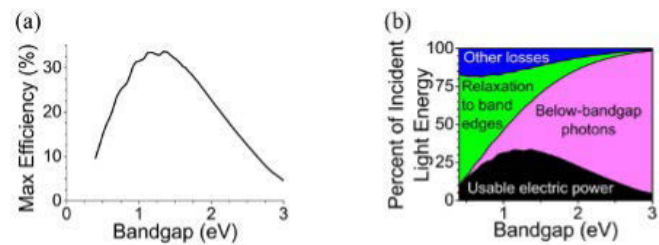


Figure 2. (a) Shockley-Queisser detailed balance limit and maximum theoretical Power Conversion Efficiency (PCE) in a simple p-n junction solar cell, (b) breakdown of other loss mechanisms contributing to lowered PCE [4].

During the last two decades, there have been numerous efforts in order to reduce the electrical, optical, and thermal losses in the solar cells, with the aim of increasing their power conversion efficiency. Silicon solar cells are dominating the solar energy market mainly due to two reasons: 1) the maturity of the technology for the development of Silicon solar cells, and 2) availability and abundance of the semiconductor materials, resulting in lower production cost for large-scale fabrication of these devices. Moreover, a reliable power conversion efficiency of silicon, had made it a favorable choice for design and fabrication of industry-scale photovoltaic panels. However, due to the relatively low power conversion efficiency (around 25% in practice) of silicon-based solar cells, it has become necessary to investigate other suitable materials which can replace Silicon with better performance, higher PCE, and possibly similar or lower cost. Figure 3 shows the research completed since 1993 done to investigate different materials and structures to achieve higher power conversion efficiency higher than 25% achieved for Silicon solar cells [5]. Copper indium gallium selenide (CIGS) with tunable bandgap energy of 1–1.7 eV is used to fabricate thin-film flexible solar cells. In [6], CIGS solar cells are fabricated on flexible copper foil and graphene has been used as hole transport layer, resulting into power conversion efficiency of 9.91%. Recently, T. Kato et al. at Solar Frontier Inc. have achieved a record high power conversion efficiency of 22.9% in development of a 1 cm<sup>2</sup> CIGS (Cu(In<sub>1-x</sub>Ga<sub>x</sub>)(Se,S)<sub>2</sub>) solar cells, in which alkali treatment using cesium on the solar cells has led to a boost in device performance [7].

Cadmium telluride (CdTe) based solar cells are also of interest due to their potential lower production cost than silicon-based solar cells, and comparable power conversion efficiency with that of Silicon-based devices.



## A Review of Schottky Junction Solar Cells

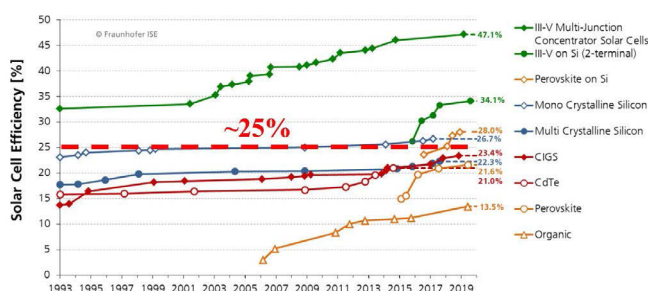


Figure 3. Achieved practical efficiency of solar cells with different semiconductor materials and structures. The red dashed line represents the average PCE of Silicon solar cells [5].

First Solar Inc. announced in 2014 to have built CdTe-based solar cells with record high PCE of 21% certified for industrial and large-scale fabrication [8]. However, due to the environmental concerns because of potential toxicity of Cd, and also the usage of rare-earth element such as tellurium, CdTe may face difficulties and limitations in large-scale fabrication over a long period of time [9].

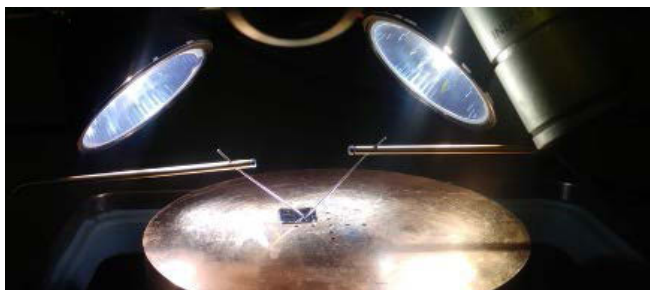


Figure 4. Experimental setup for electrical characterization of solar cells under standard illumination condition.

In recent years, organic or hybrid solar cells, in which an organic-based material (usually polymer) is used in either one or all light-absorbing active layers of the solar cell structure, are being investigated due to their interesting electrical and optical properties, such as transparency, flexibility, lightweight, and more importantly, easier fabrication process, which enables large-scale fabrication of these solar cells. In [10], a new polymer donor, called as PBDB-T-SF is used to fabricate fullerene-free organic solar cells with thickness of around 100-200 nm and record high PCE of 12-13.1%. One of the major disadvantages of organic solar cells is short-lifetime of these devices, mainly due to deterioration of the organic material which can possibly reduce the rate of photo-generated current. There are several solutions in order to address the short lifetime of organic solar cells, such as using

inverted structure, encapsulation using an insulating material, and other optimized processing steps, which will be discussed accordingly in the subsequent sections.

### III. Schottky Junction Solar Cells

Multi-junction solar cells with sub-cells made of semiconductors with different bandgap energies, are usually based on  $p-n$  junction. In this structure, the potential difference between Fermi levels of an  $n$ - and  $p$ -type semiconductor leads to creation of an electric field and built-in voltage at the junction interface. Photo-generated carriers are then separated by the electric field and extracted from the depletion region, leading to flow of the current. In a multi-junction structure, each sub-cell is basically a single  $p-n$  junction, where photons with the energy near to the band edge of the semiconductor are absorbed.

However, there are several theoretical and practical limitations in the design and fabrication of multi-junction solar cells based on  $p-n$  structure in order to achieve high power conversion efficiency. For example, the current mismatch between different layers in a multijunction solar cells leads to severe degradation in the efficiency of these devices. Also, producing the required doping level, especially  $p$ -type doping, for wide-bandgap semiconductors has often been accompanied with difficulties, such as impurity incorporation and crystal defects formation, all which can act as recombination centers within the material, and thus negatively impact the photovoltaic response of the solar cell [11].

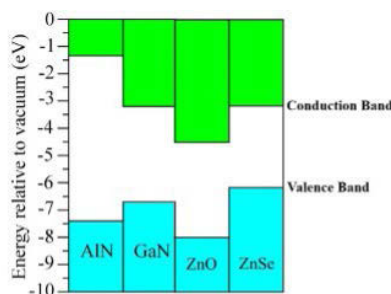


Figure 5. Valence and conduction energy bands for some of the wide-bandgap III-V compound semiconductors. Hole localization due to deep valence band leads to difficulty in producing high  $p$ -type conductivity in these wide-bandgap semiconductors.

Figure 5 shows the energy levels of conduction and valence bands of some of the wide-bandgap compound semiconductors. In these semiconductors, deep valence band leads to localization of holes with high ionization energy. Therefore, they cannot be used as free charge carriers in solar cells and contribute to



photo-generated current [12]. This leads to difficulties in producing highly efficient  $p^+$  or  $n^+$  doped layers to be used as active, tunneling, or metallization contact junctions in solar cells.

In Schottky junction solar cells, an interface between a thin conducting film and a semiconductor, provides the necessary depletion region (band bending) for separation of photo-generated electron-hole pairs, which leads to generation of photo-current. Figure 6 shows the difference of operation between a conventional  $p$ - $n$  junction and a Schottky junction solar cell. An abrupt potential barrier is created at the interface of this junction due to: 1) difference in the energy levels between Fermi level of the metal and conduction band of the semiconductor instead of the transitional energy barrier observed at the interface of a  $p$ - $n$  junction, and 2) pinning of the edge of Fermi level to specific energy levels.

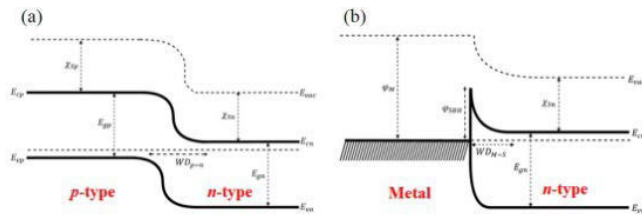


Figure 6. Band structure of a typical (a)  $p$ - $n$  junction, and (b) metal-semiconductor Schottky junction solar cell at zero bias voltage.

The use of Schottky junction solar cells can eliminate the need for the use of highly doped  $p$ -type semiconductor, and therefore potentially improve the photovoltaic response of the solar cell. Moreover, manufacturing Schottky solar cells may prove to be cost-effective and industry scalable, since fewer and simpler processing steps are required that result into lower total production cost [13].

The depletion region for a  $p$ - $n$  and Schottky structure can be calculated using:

$$WD_{pn} = \sqrt{\frac{2\epsilon_s}{q} \left( \frac{1}{N_a} + \frac{1}{N_d} \right) (\phi - V_a)} \quad (1)$$

$$WD_{MS} = \sqrt{\frac{2\epsilon_s}{q} \left( \frac{1}{N_d} \right) (\phi - V_a)} \quad (2)$$

where  $WD$  is the width of the depletion region,  $\epsilon_s$  is the permittivity of the semiconductor,  $N_a$  and  $N_d$  are acceptor and donor concentrations,  $\phi$  is the built-in potential, and  $V_a$  is the forward or reverse applied voltage.

Narrower depletion region in Schottky junction solar cells leads to lower Schottky barrier height and higher dark reverse leakage current, mainly due to thermionic-field-emission (TFE) which results in a deterioration of the photovoltaic characteristics. This typically reduces the efficiency of Schottky junction solar cells compared to  $p$ - $n$  junction solar cells. Therefore, a trade-off exists between the choosing the suitable material and the structure of the solar cell in order to achieve the optimized photovoltaic response in the Schottky solar cells.

The concept of Schottky junction solar cells have been widely used to design and fabricate high efficiency solar cells. For example, researchers have fabricated Schottky solar cells by deposition of 80 nm Indium Tin Oxide (ITO) on  $n$ -GaAs substrate [14]. However, a large dark reverse leakage current density ( $\sim 10^{-2}$  mA/cm<sup>2</sup>), mainly caused by (1) thermionic emission at the Schottky barrier, (2) higher carrier recombination rate due to crystal defects at the interface, and (3) Schottky barrier height inhomogeneity, limits the efficiency of these solar cells to less than 1%.

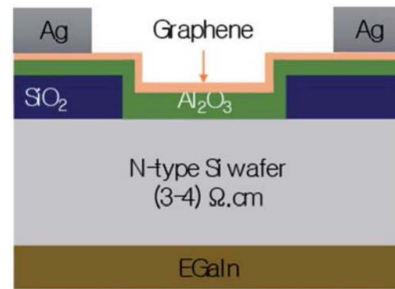


Figure 7. Schematic structure of Schottky graphene/ $n$ -Silicon Schottky solar cells with 2nm ALD-grown passivation layer [17].

The dark reverse leakage current at Schottky junctions can be lowered by using passivation layer, which can reduce the recombination of charge carriers [15].  $Al_2O_3$  with thickness of 5 nm has been used at Au/Ti/ $n$ -GaAs Schottky junctions and has reduced the leakage current density from  $7.3 \times 10^{-8}$  to  $1.2 \times 10^{-14}$  mA/cm<sup>2</sup> and increased the Schottky barrier height from 0.77 eV to 1.18 eV [16]. Similarly, a 2 nm  $Al_2O_3$  has increased the power conversion efficiency of graphene/ $n$ -Silicon Schottky solar cell from 7.2% to 8.7% [17]. Figure 7 shows the schematic structure of the Schottky solar cell, where the application of  $Al_2O_3$  passivation layer has led to improvement in photovoltaic response. Ghods et al. have similarly used the concept of field-effect passivation for reducing the leakage current in metal/ $n$ -GaAs Schottky junction solar cells [18]. In this

## A Review of Schottky Junction Solar Cells

approach, the electric field that is generated by the fixed negative charges, existing at the interface of the passivation layer and the  $n$ -GaAs semiconductor layer, keeps the free charge carriers away from the surface of the semiconductor where they can be trapped and non-radiatively recombined.

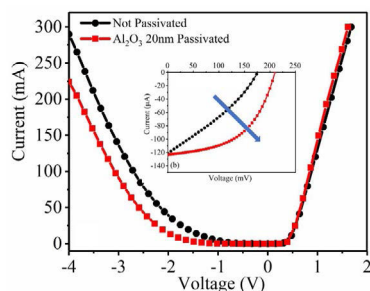



Figure 8. Current-voltage characteristics of metal/ $n$ -GaAs Schottky junction solar cells without and with  $\text{Al}_2\text{O}_3$  passivation layer. Inset shows the zoomed-in current-voltage characteristics in the forward voltage region [18].

Ultrathin films of  $\text{Al}_2\text{O}_3$  were grown using atomic layer deposition and used as the passivation layer in this structure. Figure 8 shows the current-voltage characteristics of the metal/ $n$ -GaAs Schottky junction solar cells without and with the  $\text{Al}_2\text{O}_3$  passivation. A notable reduction in the leakage current in the reverse voltage region, in addition to an increase in the open-circuit voltage is observed for the passivated solar cell. The proposed strategy shows the effectiveness of the passivation layer to improve both the diode-like and photovoltaic properties of the Schottky solar cells [18].

## IV. SUMMARY AND CONCLUSIONS

Recent advances in design and fabrication of high efficiency solar cells have focused on semiconductor materials beyond silicon, and structures beyond p-n junction. Schottky junction solar cells, which are based on the interface of a thin conducting film with a high work function and a semiconductor layer, are receiving much attention due to their ability to produce a reasonable power conversion efficiency. Additionally, a simple and cost-effective fabrication process, makes the Schottky junction solar cells suitable for use in large-scale photovoltaic devices. However, a narrower depletion region width and higher leakage current, reduces the overall power conversion efficiency of Schottky solar cells compared to p-n junction solar cells. Recent studies have shown that surface passivation is an effective approach in reducing the density of surface defects at or close to the metal-semiconductor interface, which eventually, results into improved diode-like and photovoltaic properties of Schottky junction solar cells. 

## REFERENCES

- [1] J. Rogelj, M. den Elzen, N. Hihne, T. Fransen, H. Fekete, H. Winkler, R. Schaeffer, F. Sha, K. Riahi, and M. Meinshausen, "Paris Agreement Climate Proposal Need a Boost to Keep Warming Below 2 °C" *Nature*, 534, 631-639 (2016).
- [2] U.S energy Information Administration, Monthly Energy Review, [\[Online\]](#) (2019).
- [3] M. A. Green, "Enhancement of Schottky Solar Cell Efficiency Above its Semiempirical limit", *Appl. Phys. Lett.*, 27, 287-288 (1975).
- [4] W. Shockley, "The Shockley-Queisser Limit", *J. Appl. Phys.*, 32, 510-519 (1961).
- [5] Fraunhofer Institute for Solar Energy Systems, Photovoltaic Report. [\[Online\]](#) (2020).
- [6] J. K. Sim, S. Kang, R. Nandi, J. Y. Jo, K. U. Jeong, and C. R. Lee, "Implementation of Graphene as Hole Transport Electrode in Flexible CIGS Solar Cells Fabricated on Cu Foil", *Solar Energy*, 162, 357-363 (2018).
- [7] T. Kato, J. L. Wu, Y. Hirai, H. Sugimoto, and V. Bermudez, "Record Efficiency for Thin-Film Polycrystalline Solar Cells Up to 22.9% Achieved by Cs-Treated  $\text{Cu}(\text{In},\text{Ge})(\text{Se},\text{S})_2$ ", *IEEE J. Photovolt.*, 9, 325-330 (2019).
- [8] First Solar, "First Solar Builds the Higher Efficiency Thin Film PV Cell on Record" [\[Online\]](#), 2014, Accessed June 30 2019.
- [9] V. M. Fthenakis, "Life Cycle Impact Analysis of Cadmium in CdTe PV Production", *Renew. Sustain. Energy Rev.*, 8, 303-334 (2004).
- [10] W. Zhao, S. Li, H. Yao, S. Zhang, Y. Zhang, B. Yang, and J. Hou, "Molecular Optimization Enables Over 13% Efficiency in Organic Solar Cells", *J. Am. Chem. Soc.*, 139, 7148-7151 (2017).
- [11] Chris G. Van de Walle and J. Neugebauer, "Defect, Impurities and Doping Levels in Wide-Band-Gap Semiconductors", *Brazil. J. Phys.*, 26, 163-168 (1996).
- [12] J. L. Lyons, A. Janotti, and C. G. Van de Walle, "Effects of Hole Localization on Limiting  $p$ -type Conductivity in Oxide and Nitride Semiconductors", *J. Appl. Phys.*, 115, 012014 (2014).
- [13] D. Pulfrey, "MIS Solar Cells: A Review", *IEEE Trans. Electron. Dev.*, 25, 1308-1317 (1978).
- [14] H. S. Kim et al., "Indium-Tin-Oxide/GaAs Schottky Barrier Solar Cells with Embedded InAs Quantum Dots", *Thin Sol. Films*, 604, 81-84 (2016).
- [15] H. He et al., "13.7% Efficiency Graphene-Gallium Arsenide Schottky Junction Solar Cells with a P3HT Hole Transport Layer", *Nano Energy*, 16, 91-98 (2015).
- [16] A. Turut et al., "Capacitance-Conduction-Current-Voltage Characteristics of Atomic Layer Deposited  $\text{Au}/\text{Ti}/\text{Al}_2\text{O}_3/\text{n-GaAs}$  MIS Structures", *Mater. Sci. Semicond. Process.*, 39, 400-407 (2015).
- [17] A. Alnuaimi et al., "Interface Engineering of Graphene-Silicon Schottky Junction Solar Cells with an  $\text{Al}_2\text{O}_3$  Interfacial Layer Grown by Atomic Layer Deposition", *RSC Adv.*, 8, 10593-10597 (2018).
- [18] A. Ghods, V. G. Saravade, C. Zhou, and I. T. Ferguson, "Field-Effect Passivation of Metal/ $n$ -GaAs Schottky Junction Solar Cells Using Atomic Layer Deposited  $\text{Al}_2\text{O}_3/\text{ZnO}$  Ultrathin films", *J. Vac. Sci. Technol.*, 38, 012406 (2020).



**Dr. Amirhossein Ghods** is currently a member of technical staff in Park Systems, Inc., working on developing the next generation of high-resolution atomic force microscopy systems. He received his PhD degree in electrical engineering from Missouri University of Science and Technology in May 2020. His research expertise

is in design, fabrication, and characterization of novel optoelectronic devices, including solar cells and light-emitting diodes, and has resulted in over 30 peer-reviewed journal publications, conference proceedings, and book chapters. He was also working as a research intern at Facebook AR/VR during summer 2019. His research was mostly focused on characterization of leakage current in blue GaN light-emitting diodes.



**Dr. Chuanle Zhou** is currently assistant research professor at Missouri University of Science and Technology (Missouri S&T). Her research expertise is in characterizing compound semiconductor electrical, thermoelectrical, optical and magnet properties and using these materials to fabricate devices for

applications in the areas of sensors, illumination, energy harvesting, and spintronics. She has given presentations and invited talks in conferences of various areas, including American Physical Society (APS) March Meeting, International Conference on Thermoelectrics (ICT), SPIE conference, IEEE Photovoltaic Specialists Conference (PVSC), etc. She has had active collaboration with research groups from Purdue, Northwestern University and UNC Charlotte. Her research resulted in over 40 publications, conference proceedings, books, book chapters, and patents.



**Dr. Ian Ferguson** is the Dean of Southern Polytechnic College of Engineering and Engineering Technology at Kennesaw State University. Prior to joining Kennesaw, he had leadership positions in both academia (Imperial College, Northwestern University, Georgia Tech, UNC Charlotte, Missouri

S&T, etc.) and industry (GEC, EMCORE, etc.). His research expertise is in building interdisciplinary teams to use compound semiconductor materials and devices for applications in the areas of sensors, illumination, energy harvesting, and spintronics. As an international educator and researcher, he has had active collaborations in the US, Europe, and Asia, which has resulted in over 550 refereed journal publications, conference proceedings, books, book chapters, and patents. He is Fellow of the Royal Society of Arts, Manufactures and Commerce (FRSA), the Institute of Electrical and Electronic Engineering (IEEE), the Institute of Physics (IOP), the Optical Society of America (OSA) and the International Society for Optical Engineering (SPIE).

<sup>1</sup>Electrical and Computer Engineering, Missouri University of Science and Technology, Rolla, MO 65409, USA

<sup>2</sup>Southern Polytechnic College of Engineering & Engineering Technology, Kennesaw State University, Marietta, GA 30060, USA

## IEEE-HKN PATHWAYS Industry

IEEE-HKN Member Benefit

### IEEE-HKN's Premier Event That **Connects You** With Industry Experts

Get ready to hear from the experts on how to plan and manage your career, how to stand out as you search for a job, and what's next in tech. Watch or rewatch one, two or all of the free webinars now available on demand.

- How to Stand Out and Own Your Career Search in a Virtual World!
- Impacts and Opportunities for a Better Tomorrow
- 12 Key Insights to Career Management
- Succeed as an Entrepreneur
- What They Didn't Teach You in Engineering School
- Acing the interview!
- How to Land a Dreamy Enterprise Computing Job
- Start-Ups and Creative Applications of Technological Skills

Sessions Are Free and On Demand

Watch On Demand





# IEEE Solid-State Circuits Society: Shaping the IC and Electronics World

By Abira Altvater, Technical Community Program Specialist and Adam Greenberg, Society Executive Director

The [IEEE Solid-State Circuits Society \(SSCS\)](#) focuses on the design, implementation, and application of solid-state integrated circuits. With over 10,000 members all around the world, SSCS' vision is to foster innovation and excellence in solid-state circuits for the benefit of humanity through education, communication, recognition, leadership opportunities, and networking.

## Stay Current

SSCS offers many member benefits. Educational offerings include online short courses, lectures, and tutorials on the [Society's Resource Center](#); live and on-demand [webinars](#); and a [distinguished lecturer program](#). SSCS membership includes a subscription to a portfolio of leading [publications](#), including the IEEE Journal of Solid-State Circuits, one of the most downloaded scholarly publications of the IEEE.



The annual SSCS Soccer and Circuits Collaboration and Education Retreat (SOCCER) brings together students from Oregon State University and Stanford University.

## Offerings for Students and Young Professionals

The Society also has many benefits for students and young professionals, including [Predoctoral Achievement Awards](#), [Student Travel Grants](#), and [Design Contests](#). In our ever-changing virtual world, SSCS now offers [mentoring](#) via an interactive online platform, allowing young professionals to connect and network with luminaries in the field. Students can showcase their creativity by entering the Society's T-shirt design contests and video contests.

## Get Connected


SSCS has a very active [Women in Circuits Committee](#) that helps enhance professional opportunities at networking events at SSCS-sponsored conferences, by holding events at local SSCS chapters, and by offering leadership activities.

To get involved on the grassroots level, members can join their local SSCS [chapters](#), a vital component of the Society that provides opportunities to participate in local activities in your area. The Society has over 120 chapters worldwide.

## Invest in Your Career

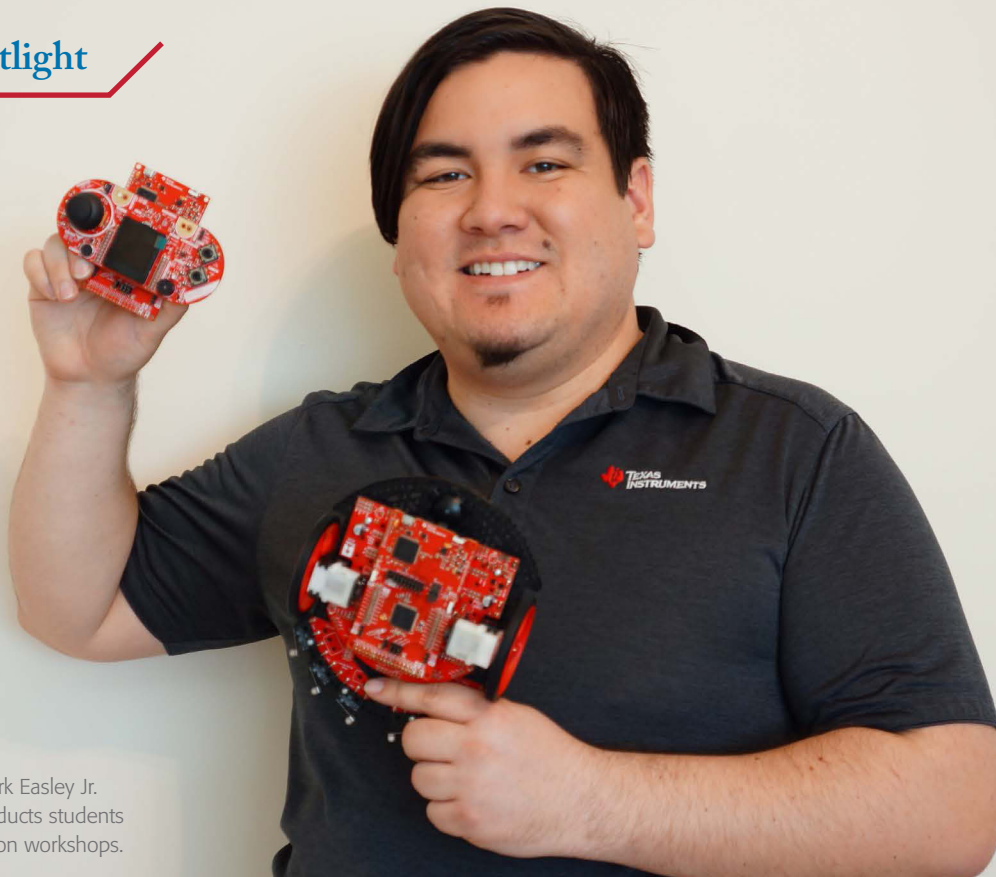
SSCS members receive favorable rates on five sponsored [international conferences](#), at which attendees participate in educational and networking sessions.

SSCS recently launched a technical committee called [Solid-State Circuits Directions \(SSCD\)](#). Its charter is to promote forward-looking topics, improve connection to developments at higher abstraction levels, and stimulate interactions with other communities. One of SSCD's main activities is holding member-driven technical workshops. Two events have been held recently, including a workshop on democratizing IC design, and one on Hardware Security.

Solid-state circuits are the heartbeat of technological innovation, from the way we entertain ourselves to the way we deal with global crises such as the COVID-19 pandemic. Join us and help make a difference. 

Enjoy **20% off SSCS membership** by entering code **SSC20DCEJAM** at checkout. This offer is valid until 1 July 2021 and for first time SSCS members.





Texas Instruments' Mark Easley Jr. shows off the two products students built as part of hands-on workshops.

## Texas Instruments and IEEE-HKN Workshops Engage with Remote Engineering Students

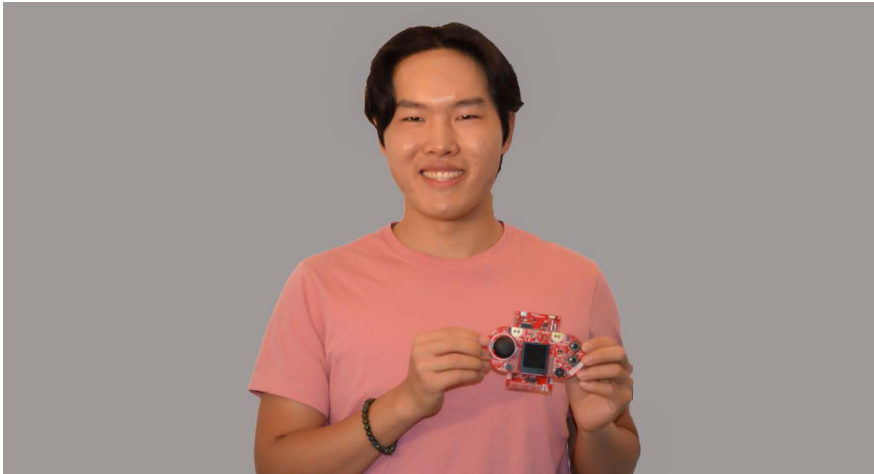
*By Mark Easley Jr., University Program Marketing Manager, Texas Instruments*

The world changed in the first months of 2020 as news of the global COVID-19 pandemic spread to all corners of the world. Fear and uncertainty rocked all aspects of life. Fundamental questions of how will everyone go to work or school safely, what equipment and provisions would be required to endure the global crisis were being asked, but answers were not easy to find. These challenges in industry required rapid change to remote work to keep operations running, but also to maintain the foundations and systems for future growth when the crisis is overcome.

Texas Instruments (TI) has a long tradition of student engagement through live workshops and technology lectures. This specialized engagement is a key facet to the TI University Program, contributing to stronger engineering student experiences that benefit customers when students enter industry, as well as future TI employees.

Through a partnership with IEEE-HKN, TI worked quickly to establish opportunities for students who were affected across the board with how and where they study. The collaboration centered around the delivery of virtual workshops, and took advantage of a variety of logistics that would enable personalized technical content at any location the student resides.

Delivering the workshop with electronics hardware and collaboration technology is one thing, but developing engaging content that would interest students in a remote context is another difficult task.



A student who took one of the hands-on workshops displays the console he built.


The initial workshop series provided comprehensive embedded systems knowledge as explained through cloud-based tools, lecture slides and a hands-on demo of a relatable subject – gaming.

Hundreds of students participated to build and demo their own handheld gaming system while gaining appreciation for advanced skills around the Internet of Things (IoT) and specific real-time operating systems necessary for engineers.

Following the success of the workshops held in the third quarter of 2020, TI expanded the workshop into February and March of 2021 to include content focused on robotics and automation.

Seeking to challenge students with strong technical concepts relevant for entry into industry, while keeping to a compressed virtual schedule, company organizers took learnings from the initial IEEE-HKN workshops and applied better tactics to engage students throughout the duration of each session.







Incorporating more of a social environment with participant introductions, video transitions and ice-breaker activities, students realized the workshops covered material and perspectives they often can't get in the classroom.

Proven as a successful model for both the participants and TI, the partnership with IEEE-HKN plans to offer more virtual workshop sessions in the future. The workshops will include additional technical topics related to trends facing the industry around IoT, artificial intelligence, machine learning and power electronics. Additionally, organizers are considering the format to deliver these technical workshops as fully virtual, hybrid and live in-person events. 



## TAP. CONNECT. NETWORK. SHARE.

**Connect to IEEE—  
no matter where you  
are—with the IEEE App.**

-  Stay up-to-date with the latest news
-  Schedule, manage, or join meetups virtually
-  Get geo and interest-based recommendations
-  Read and download your IEEE magazines
-  Create a personalized experience
-  Locate IEEE members by location, interests, and affiliations



**Download Today!**







### Hannah Schroeder

Epsilon Epsilon  
University of Houston

Hannah Schroeder is a senior in Electrical Engineering at the University of Houston. She grew up in the suburb of Friendswood, Texas, and has had a lifelong penchant for patterns and computers. When Hannah originally entered college, she pursued a major in Vocal Performance (i.e. classical singing). Although she loved the study of music, she discovered that pursuing a career in either music education or performance was unappealing. She decided to change her major after two semesters. Since then, Hannah has found more peace and success in an analytical field. Although it was not her initiative to restart the Epsilon Epsilon Chapter of IEEE-HKN, which had been inactive for roughly 10 years, Hannah was the first Chapter President to direct the planning of any Chapter events, establish regular meetings between officers, and set up several long-lasting Chapter practices and documents to support future members. The Epsilon Epsilon Chapter has grown rapidly since its inception. Its first new members were inducted in December 2019, and by October 2020, the Chapter was hosting an event roughly every two weeks. The Chapter is now reaching out to students outside of the Engineering college in Engineering Technology and Computer Science, and aims to establish a well-known, welcoming, and exciting presence on the UH campus. In addition to her work with HKN, Hannah is also a National Merit Scholar and the recipient of two UH Engineering Alumni Association awards. She also is an active writer and actor in the Honors College theater club.

#### What has it meant to you to be inducted into IEEE-HKN?

Quite a bit! At UH, many of our engineering student organization meetings can be large and intimidating, but with HKN, it's much easier to get to know people. It's especially beneficial to be around people who are in the same major, at the same level, and who have similar personalities to you. I have also gained an incredible amount of resourcefulness and self-confidence by taking on a leadership role in HKN, and I believe I would be a dramatically different person today had I shied away from this position.

#### Do you have a best HKN story to share?

I have two! I thoroughly enjoyed the 2019 Student Leadership Conference (SLC). At that point, I was the Vice President of the Chapter, and we were still figuring out what our HKN Chapter should look like. We had our first induction later that semester. I talked to so many people during the SLC, and got some great ideas and advice about how to run an HKN Chapter. We hung out quite a bit with the Kappa Psi Chapter from UCSD -- special thanks to them! My other favorite event is Epsilon Epsilon's first real event: a tutoring and study session for Circuits 1 and 2 students that took place in February 2020. We had roughly 25 members at the time, all inducted in December 2019, and about half of them showed up to volunteer at our first event. It warmed my heart so much to see that much enthusiasm, especially when we were such a young chapter.

#### Why did you choose to study the engineering field?

I grew up around engineers, so engineering always seemed like a viable career path for someone who was, and is, a big nerd. However, I wanted to pursue a career that I loved emotionally, so I initially chose to study music in college. I eventually realized, though, that I missed the more analytical thinking of one of the STEM disciplines, and that I could still love music without tying it to my personal finances. That's not to say I don't love engineering, I do! I just didn't realize until later that the satisfaction of working on a problem was an emotion worth exploring. I had often dismissed that satisfaction as pretentiousness

or conflated it with the feeling of success in general. I didn't realize until later that I did like solving problems, even if that realization felt very nerdy to admit.

### What do you love about engineering?

I love nitpicking a design and fine-tuning it until it works seamlessly. I also really like looking at things that have some kind of intuitive symmetry, or solutions that are elegant and simple. My favorite projects are those that require my full imagination and usually involve writing some code, such as my FPGA projects. You can tell I'm enjoying a project when I have several barely-comprehensible sketches next to me, I spend too much time making tiny changes to it, or I lose track of time while working on it.



Hannah Schroeder takes a selfie with fellow Epsilon Epsilon Chapter members.

### What is your dream job?

I'm hesitant to pick a definitive or narrow field right now. I tried that with music. At the moment, I love learning about computer hardware, especially processors, and I know I would find success in a fast-moving industry. My dream job is one that is exciting enough to keep me learning new things, but comfortable enough so that I can have confidence in my own work.

### Whom do you admire and why?

I once told one of my high school music teachers that I had been very frustrated with a passage of music, but had kept practicing it anyway. He gave me a funny look and said something similar to "Why? If you're frustrated, put it down and come

back to it later." He was a very accomplished musical professional, so at first it struck me as odd that he was not constantly pushing through frustration and stress to become successful.


### What is the next BIG advance in engineering?

If the scientific community can get nuclear fusion figured out, we could seriously reduce the effects of energy generation (especially burning fossil fuels) on the climate. However, if we want to tackle climate change, there are a variety of political and economic solutions that we could implement immediately. I don't think we have to wait for a big advance in engineering to solve this problem.

### What is the most important thing you've learned in school?

After going through four years of engineering, I have become more comfortable with being in new situations or dealing with new information. When you're a perfectionist with a long history of success in very structured environments, discomfort in new situations is normal, and even expected. Being the President of a Chapter with zero established structure definitely forced me to put my anxiety aside and forge into unfamiliar territory, using my intuition and guidance from others. I even discovered a great deal of freedom in the ability to write the rules yourself. Since then, I've gotten a lot better at researching topics outside of class, picking up new hobbies, and pushing myself outside my comfort zone.

### What advice would you give to other students entering college and considering studying your major?

Say yes to things as often as you can, even if they are intimidating! My Physics 1 professor asked me to do research with him my freshman year, and I said no because it wasn't my field. I still regret that. I was a freshman in Physics 1, nothing was "my field!" Also, take the time to get involved! It will take effort and may be uncomfortable, but you will pick up a lot of second-hand knowledge not taught in class, as well as make good friends and study buddies. 

The IEEE-Eta  
Kappa Nu Board  
of Governors  
*cordially invites*  
the members  
of the 2021  
Graduation Class,  
Family, & Friends  
*to the*



# IEEE-HKN Graduation CELEBRATION

Saturday, 5 June 2021  
2 pm (ET)

The event will include a virtual procession of the members of the Class 2021, the presentation of the Outstanding Chapter Awards, remarks from the 2020 Outstanding Student Award recipient, and the elevation of Dr. Maxine Savitz, Vice President, National Academy of Engineering, to HKN Eminent Member.  
*More details to come.*

**REGISTER HERE**



<https://event.on24.com/wcc/r/3010208/2CA812A5197EA0E891F4DA6FBD2AE403>





# THE BRIDGE Magazine of IEEE-Eta Kappa Nu: Part II

By Steve E. Watkins, Gamma Theta Chapter

**THE BRIDGE** magazine was named for the emblem of IEEE-Eta Kappa Nu (HKN) – the Wheatstone bridge. Just as this emblem reflects the three ideals for member eligibility, the magazine promotes HKN and its Scholarship, Character, and Attitude values. The content includes an archival record of the global association, highlights of Chapter activities, recognition of technical achievements, historical notes for the profession, and other content of interest to student and professional members.



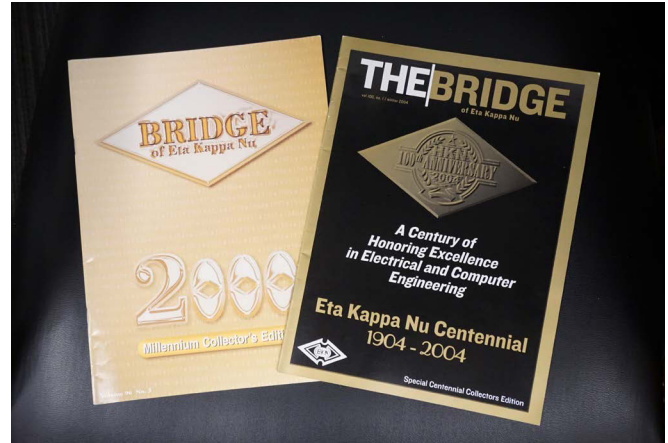
THE BRIDGE on the IEEE App

recently was added to the IEEE app for even easier access via mobile devices.

As the official publication of IEEE-HKN, the magazine was and is a primary means of informing both student and alumni members about activities of the Society. Board elections, new Chapters, award presentations, and conferences are examples. It also serves to note significant Chapter activities. Alton B. Zerby, Executive Secretary 1934-1958, considered the magazine "a vehicle of communication between students and alumni."

Chapter submissions were an essential part of the magazine content. The HKN Constitution from 1958 required officer teams to include a Bridge Correspondent and identified these Chapter officers as supporting staff to the publication's editor. The duties for Bridge Correspondent were to "submit reports of the Chapter's activities to *THE BRIDGE* and perform

all other duties pertaining to *THE BRIDGE*, including publicity for the Chapter" (Article II, Section 9, E.). While this position is no longer required, Chapters are encouraged to submit significant Chapter news and events for possible publication. In particular, Chapter celebrations of Founders Day are highlighted each year.




THE BRIDGE Covers for the Millenium (2000) and Centennial (2004) Issues

Covers for key historical issues are shown above. The Millennium issue (Vol. 96, No. 3, 2000) reprints selected content of *THE BRIDGE* from 1909 to 1995. The Centennial issue (Volume 100, No. 1, 2004) along with the Diamond Jubilee issue (Volume 75, No. 2, 1980) preserve a wealth of historical information and photographs for the Society. Lists of HKN leaders, Eminent Members, and award winners are included. Scans of these print issues are available at the archive on the Engineering and Technology History Wiki page [https://ethw.org/Eta\\_Kappa\\_Nu](https://ethw.org/Eta_Kappa_Nu).

*THE BRIDGE* accepted advertising starting in 1917 as a connection to industry. Companies such as General Electric, Westinghouse, NRC, and Hughes Aircraft were frequent sponsors. Educational connections have become important recently, with universities promoting their graduate programs. These university sponsors are also shown on the IEEE-HKN website.

A major portion of recent issues have included original feature articles and a few reprinted articles from IEEE publications. These features are intended to give readers insight into technical and professional subjects of interest. Each issue has a theme, and several issues were organized by guest editors. The issue themes and an index of feature articles that have appeared in *THE BRIDGE* for 2013 to 2020 are listed below. Reprint articles are noted.

**About the Author:** Steve E. Watkins was the 2018 President of IEEE-Eta Kappa Nu and is co-Editor-in-Chief for *THE BRIDGE*. He was inducted by the Gamma Theta Chapter at Missouri University of Science and Technology. He is professor at Missouri S&T and has been a Faculty Advisor for the Gamma Theta Chapter since 1992. 

## Index of Feature Articles in *THE BRIDGE* Magazine of IEEE-HKN since 2013

### Volume 109, 2013

#### Issue 1, Theme: *Engineering for Space Applications*

- "123 Million Miles in Space and 12 Miles in LA Traffic," Burt Dicht.
- The Mission and Engineering Challenges of the James Webb Space Telescope," Jonathan Arenburg.
- "The Universe in a Supercomputer," Joel R. Primack (Reprint).
- "Deflecting Asteroids," Gregory L. Matloff (Reprint).

#### Issue 2, Theme: *Engineering Ethics*

- "Creating the IEEE Code of Ethics: The History Behind the Process," Emerson W. Pugh.
- "Lessons from the Storm (Hurricane Katrina)," Byron Newberry.
- "Professional and Ethical Dilemmas in Software Engineering," Brian Berenbach and Manfred Broy (Reprint).
- "Are There Experts in Engineering Ethics," Karl D. Stephan (Reprint).
- "Preparing for High Ethical Standards," Steve Starrett.

#### Issue 3, Theme: *Celebrating Engineering Accomplishments*

- "Bridges I have Crossed," Thomas B. Greenslade, Jr.
- "Bistatic Radar," Hugh Griffiths.
- "Designing the First Microprocessor," Marcian E. Hoff (Reprint).
- "An Early History of the Internet," Leonard Kleinrock (Reprint).

### Volume 110, 2014

#### Issue 1, Theme: *Lasers, Optics, and Photonics*

- "Laser Safety for Electrical Engineers," David Brown.
- "Quantum Optics for the 21st Century Electrical Engineer," Sean J. Bentley.
- "Smart Bridges using Fiber Optic Sensors," Steve E. Watkins (Reprint).
- "A Brief History of High-Power Semiconductor Lasers," David F. Welch (Reprint).

#### Issue 2, Theme: *Engineers' Involvement in Society*

- "Can IEEE Save the World," Moshe Kam.
- "Aiding Autism Through Technology," Sampathkumar Veeraraghavan and Karthik Srinivasan.
- "Wearable Sensors and Systems," Paolo Bonato (Reprint).
- "Influencing Public Policy," Russell T. Harrison.

#### Issue 3, Theme: *Spotlight on Student undergraduate Research*

Guest Editor: Keenan Johnson.

- "Utilizing Computational Electromagnetics for the Advancement of Photonic Processor Communications," Jelena Notaros.
- "New Completion-Tree Topology for Quasi-delay Insensitive Logic," Anjian Wu and Alain J. Martin.
- "Telemetry Processor for a Remotely Operated Vehicle," Keenan Johnson.
- "GazePointer: Computer Vision Based Eye Gaze Tracking for Human-Computer Interaction," Muhammad Usman Ghani and Muhammad Adnan Siddique.
- "Trial by Fire," Robin R. Murphy (Reprint)

**HKN History Note:** Interest was sufficient to offer a lifetime subscription plan starting in 1935.

HKN founders Maurice L. Carr and Edmund B. Wheeler were Life Subscribers Number 1 and 2, respectively.

### Volume 111, 2015

#### Issue 1, Theme: *Smart Grid and Renewable Energy*

- "The Big Picture: Smart Research for Large-Scale Integrated Smart Grid Solutions," Mladen Kezunovic, Vijay Vittal, Sakis Meliopoulos, and Tim Mount (Reprint).
- "Growing the Smarter Workforce," Peter W. Sauer.
- "Interconnection of Renewable Energy to the Power Grid," Vincent J. Forte.
- "Smart Grid – Safe, Secure, Self-Healing," S. Massoud Amin and Anthony M. Giacomoni (Reprint).
- "Smart Grid: The Role of the Information Sciences," H. Vincent Poor.

#### Issue 2, Theme: *Autonomous Vehicles*

- "A 13,000km Intercontinental Trip with Driverless Vehicles: The VIAC Experiment," Massimo Bertozzi, Alberto Broggi, Alessandro Coati, and Rean Isabella Fedriga (Reprint).
- "'Drones' and the Future of Domestic Aviation," John Villasenor (Reprint).
- "Sensors Technologies for Intelligent Vehicles Perception Systems: a Comparison Between Vision and 3DOLIDAR," Alberto Broggi, Paolo Grisleri, and Paolo Zani.
- "SeaPerch – On the Yellow Brick Road," Susan Giver Nelson.

#### Issue 3, Theme: *Focus on IEEE-HKN*

- "Suggestions for Electrical Research in Engineering Colleges," V. Karapetoff (Reprint).
- "A Tale of Two Cities: Biosensor Engineering for Water Management," Evgeni Eltzov, Adarina Low Yuen Kei, and Robert S. Marks.
- "Special History Section."

### Volume 112, 2016

#### Issue 1, Theme: *Biologically Inspired Engineering*

Guest Editor: Jacquelyn K. Nagel.

- "Application of Natural Systems to Engineering at NASA," Kennie H. Jones, George M. Studor, and Jacquelyn K. Nagel.
- "Auto-Gopher 2 – a Biologically Inspired Deep Drill for Planetary Exploration," Yoseph Bar-Cohen, Kris Zacny, Mircea Badescu, Hyeong Jae Lee, Stewart Sherrit, Xiaoqi Bao, Gale L. Paulsen, and Luther Beegle.
- "Leveraging Nature's Gifts in the Design of Control Systems," Mark Kerbel.
- "Design of a Bio-inspired Optical Current Transducer," Jacquelyn K. Nagel and Steve E. Watkins.
- "Dinosaurs Make Light Work – From the Engineering Problem to an Innovative Lightweight Product," Hans-Joachim Weber and Martin Weber.

**Issue 2, Theme: Cybersecurity**

Guest Editor: Egemen K. Cetinkaya.

- "Cyber-Physical Security Assessment (CyPSA) for Electric Power Systems," Katherine R. Davis, Robin Betthier, Saman A. Zonouz, Gabe Weaver, Rakesh B. Bobba, Edmund Rogers, Peter W. Sauer, and David M. Nicol.
- "Security Analytics: Essential Data Analytics Knowledge for Cybersecurity Professionals and Students," Rakesh Verma, Murat Kantarcioglu, David Marchette, Ernst Leiss, and Thammar Solorio.
- "A Brief Review of Security in Emerging Programming Networks," Egemen K. Cetinkaya.

**Issue 3, Theme: Sensors and Sensing**

- "Terahertz Range Weak Reflection Optical Fiber Structures for Distributed Sensing," Zhen Chen, Gerald Heffernan, and Tao Wei.
- "Mechantronic Design of an Actuated Biomimetic Length and Sensor," Kristen N. Jaax and Blake Hannaford.
- "Unconventional Biosignal Sensing with Passive RFID Tags," Shrenik Vora and Timothy P. Kurzweg.

**Volume 113, 2017****Issue 1, Theme: UAVs**

- "Intel: Breaking Ground in the Drone Industry," Joan Tafoya.
- Safety and Privacy Policy Regarding Unmanned Aerial Vehicles (UAVs)," Logan T. DiTullio.
- "Connectivity in Networked Unmanned Aerial Vehicles," Rajdeep Dutta, Zachary Ruble, and Daniel Pack.
- "A Student-Built Fixed-Wing UAS for Simulated Search-and-Rescue Missions," Chase R. Yasunaga, Kalani R. Danas Rivera, Joseph D. Harris III, Marte A. Martinez, Jr., Stephen L. J. Mau, Reyn H. Mukai, Kevin Y. Sonoda, Wayne A. Shiroma, and A. Zachary Trimble.

**Issue 2, Theme: Rebooting Computing**

- "From Ethics to Innovation: A Common Code," John C. Havens.
- "The IEEE Rebooting Computing Initiative," Elie Track and Alan Kadin.

**Issue 3, Theme: Outreach and Impact**

- "MOVE Makes a Difference," James M. Conrad, Gregg Vaughn, Grayson W. Randall, Mary Ellen Randall, and Percy F. Shadwell, Jr.
- "Project Lead the Way: A STEM Program for Electrical and Computer Engineering Students," R. Joe Stanley, Stuart Baur, and Ben Yates.
- "HKN's Greatest Asset: Alumni," Larry Dwon (Reprint).

**Volume 114, 2018****Issue 1, Theme: Quantum Entanglement and Engineering**

Guest Editor: Sean J. Bentley

- "Quantum State Generation in Optical Frequency Combs for Quantum Computing," Yanbing Zhang, Piotr Roztock, Christian Reimer, Stefania Sciarra, Michael Kues, David J. Moss, and Roberto Morandotti.
- Quantum Cryptography and Side Channel Attacks," Colin Lualdi, Stephen Pappas, Daniel Stack, and Brandon Rodenburg.
- "Quantum Teleportation from Sci-fi to the Quantum Wi-fi," Daniel Cavalcanti and Paul Skrzypczyk.

**Issue 2, Theme: Neural Networks**

- "Outsmart Moore's Law with Machine Learning," Dustin Tanksley and Donald C. Wunsch.
- Determining Optimum Drop-out Rate for Neural Networks," Josian A. Yoder.
- Distributed Stochastic Optimal Flocking Control for Uncertain Networked Multi-Agent Systems," Hao Xu and Wenxin Liu.

**Issue 3, Theme: Bridging Academic Excellence to Lifetime Excellence: Three Engineers' Roadmap to Success**

Guest Editor: Marcus Huggans

- "The Secret of Success," Jim Watson.
- Creating the Builders of Tomorrow," Shameeka Emanuel.
- My Leadership Journey," Alan Mingo.

**Volume 115, 2019****Issue 1, Theme: Making an Impact**

- Can STEAM Education Help Lift Developing Nations?" Kayla Ninh.
- IEEE-HKN Chapter and Student Branch Work Together to Increase Impact on Community," Dauda Ayanda.
- "2018 Annual Report for IEEE-Eta Kappa Nu," Steve E. Watkins.

**Issue 2, Theme: Connecting the World with Amateur Radio**

Guest Editor: Steve E. Watkins

- "Amateur Radio and Careers in Electrical and Computer Engineering," Ward Silver.
- "Electrical and Computer Engineering and Amateur Radio," Dennis Silage.
- "Great Impedance Match for Knowledge Transfer: Amateur Radio as Part of Electrical and Computer Engineering Education," Dennis Derickson, Charles "Chuck" Bland, Jack Gallegos, and Marcel Stieber.

**Issue 3, Theme: Graduate Education**

- "Why should I go to Graduate School," Karen Panetta.
- Hear it from Professionals: Lessons Learned and Advice for Graduate School."
- Graduate Student Profiles," Katelyn Brinker, Emily Hernandez, and Wendy P. Fernandez.

**Volume 116, 2020****Issue 1, Theme: Members Engaged and Inspired: 2019 in Review**

- "2019 Year in Review: Members Engaged and Inspired."

**Issue 2, Theme: Beyond Engineering: Atypical Careers and Contributions by Engineers**

- "Public Policy: A Different Way to Change the World," Russell T. Harrison.
- "Intellectual Property: What's Mine is Mine and What's Yours is Mine," Orin E. Laney.

**Issue 3, Theme: The Future of Renewable Energy: Generation, Transmission, Consumption**

Guest Editor: Roderick Jackson

- "The Future of Renewable Energy Generation: Photovoltaic Materials," Annalise Maughan, Kai Zhu, and Joseph J. Berry.
- "The Future of Renewable Energy Transmission: An Autonomous Energy Grid," Benjamin Kroposki, Andrey Bernstein, and Jennifer King.
- "The Future of Renewable Energy Consumption: Grid-Interactive Efficient Buildings," Nikitha Radhakrishnan, Erika Gupta, Karma Sawyer, and Monica Neukomm.





## Lawrence E. Tannas Jr., 84

IEEE Life Member  
UCLA

# Innovator in Electronic Displays

*Sourced from the UCLA Samueli School of Engineering*

IEEE Life Member Lawrence E. Tannas Jr., a visionary engineer who pushed the evolution of the electronic displays industry from its early days in avionics to a global presence, died 5 February 2021. He was 84.

Known as “Larry” to all, Tannas earned a bachelor’s and a master’s degree in engineering at UCLA in 1959 and 1961, respectively.


After graduation, Tannas worked in Southern California’s burgeoning aerospace industry. He developed automated landing systems at General Electric Co., designed the backup reentry-guidance display for the Apollo reentry vehicle at Honeywell International Inc., and at Martin Marietta Inc., he created a cockpit for the SV-5 manned space vehicle—an Air Force prototype that was an important predecessor to NASA’s space shuttle.

As Tannas progressed in his career, he began to specialize in technologies for flat-panel displays, in particular, liquid crystal displays (LCDs). Tannas was instrumental in the early growth of this technology and its evolution. It was his work at Rockwell Autonetics in the 1970s that established the world’s first production line for LCDs. He then perfected a manufacturing process for electroluminescent displays while at Aerojet Electro-Systems Corp.

In 1999, he founded Tannas Electronic Displays, Inc., which specialized in research, development, manufacturing and licensing of intellectual property for resizing LCDs. In 2015, he sold the company to Pixel Scientific Inc., but remained active in the industry as president of the consulting firm Tannas Electronics. Throughout his career, he was awarded 28 patents and had more than 10 others pending.

Parallel to his pioneering career, Tannas was also a proponent of elevating electronic displays, also known as information displays, to be a vibrant scientific field in its own. He was a fellow and past-president of the Society for Information Display (SID).

From 1980 to 2000, Tannas developed and taught advanced engineering classes on information displays at UCLA Extension, as well as at other institutions. He was also the author of more than 50 technical papers, and wrote and edited the first definitive book on flat-panel displays, “Flat-Panel Displays and CRTs,” published in 1983 by Van Nostrand Reinhold.

Tannas is survived by Carol, his wife of 64 years, three children, and 10 grandchildren. 

*Photo credit: UCLA Samueli School of Engineering*

## Former HKN National President

Sourced from [Tributearchive.com](https://tributearchive.com)

John E. Farley, the HKN National President in 1968 and 1969, died on 6 February 2021. He was 95 years old.


Known to his friends and family as "Jack," he spent most of his life as a resident of Park Ridge, Illinois, where he raised his family, and commuted to his offices in downtown Chicago.

Born in Chicago in November of 1925 to Miles and Bess Farley, John served in the United States Navy during WWII in the Pacific theater. He earned his bachelor's degree from the University of Illinois at Urbana-Champaign and a master's degree from Northwestern University, both in Electrical Engineering.

John was an engineer and manager for various companies within the former AT&T/Bell System, primarily at Illinois Bell Telephone. He also helped develop new communications technologies at Bell Labs in New Jersey.

John was active in promoting electrical engineering and STEM careers through his work with Eta Kappa Nu (HKN), the Electrical Engineering Honor Society, where he served as national president from 1968 to 1969. He also remained active at his alma mater, serving on the Electrical Engineering Alumni Board at the University of Illinois. He also was a co-founder of a marine instrumentation business.

His passion was sailing on Lake Michigan. He was an active sailboat racer for over 50 years. He enjoyed encouraging others to become active in the sport of sailboat racing.

He is survived by his wife, Karin (Clafford) Farley, whom he met when they were both students at the University of Illinois. He also is survived by two children, four grandchildren, and one great-grandchild. 



### John E. Farley, 95

Alpha Chapter,  
University of Illinois,  
Urbana-Champaign  
HKN National President,  
1968-1969

Photo credit: [tributearchive.com](https://tributearchive.com)

# IEEE-Eta Kappa Nu Launches IEEE-HKN Career Center

IEEE-Eta Kappa Nu



IEEE-Eta Kappa Nu is proud to announce its new IEEE-HKN Career Center—the premier resource to connect career opportunities with highly qualified engineering talent.



IEEE-HKN Career Center will allow you to:

**LOG ON TODAY!**

## **MANAGE YOUR CAREER:**

- Search and apply to more Engineering jobs than in any other job bank.
- Upload your anonymous resume and allow employers to contact you through IEEE-HKN Career Center's messaging system.
- Set up Job Alerts specifying your skills, interests, and preferred location(s) to receive email notifications when a job is posted that matches your criteria.
- Access career resources and job searching tips and tools.
- Have your resume critiqued by a resume-writing expert.

## **RECRUIT FOR OPEN POSITIONS:**

- Post your job in front of the most qualified group of Engineering talent in the industry.
- Promote your jobs directly to candidates via the exclusive Job Flash email.
- Search the anonymous resume database to find qualified candidates.
- Manage your posted jobs and applicant activity easily on this user-friendly site.



[ieee-hkn.careerwebsite.com](http://ieee-hkn.careerwebsite.com)



THE BRIDGE

HKN.ORG