International Research/education Collaboration on GaN LED/LDs between Cal Poly (USA) and PKU (China)

Xiaomin Jin [a], Xiao-hua Yu [a], Xiang-Ning Kang[b], and Guo-Yi Zhang[b]
[a]Electrical Engineering Department, 1 Grand Avenue,
California Polytechnic State University, San Luis Obispo, CA, USA, 93407-9000;
[b]School of Physics and State Key Laboratory for Artificial Microstructures and Mesoscopic Physics, Peking University, Beijing, China, 100871.

Abstract

We initiated and established an international collaboration with institution in China. This is one of the international programs at California Polytechnic state University (Cal Poly) that emphasizes on both research and educational aspects. Our international partner is Professor Guoyi Zhang in the School of Physics at Peking University (PKU), Beijing, China. This project started by the Prof. Jin's summer visit to PKU in 2006 which is supported by Wang Faculty Fellowship at Peking University in Beijing, China, 2006-2007 through California State University (CSU) International Programs, and then expanded to include several teams of Cal Poly students international visit from 2007 to 2012, which was also supported by Department of the Navy, under Award # ONR 6-N00014-07-1-1152 (2008) and Award # ONR 7-N000140811209 (2009); "ChunHui" exchange research fellow through Chinese Educational Department (2008), respectively. In summer 2009, Simeon Trieu, one of Prof. Jin's graduate students, was awarded an NSF EAPSI summer and won the 1st place CSU research competition on graduate engineering and computer engineering level in 2010, because of working on the project. Now Prof. Jin is supported by 1) NSF Grant OISE Award #1029135 from year 2010 to 2013 and 2) Chinese National Key Research Lab Collaboration Grant 2010-2011 and 2011-2012. Those grants enable Prof. Jin to bring more US students to work in China. This paper will discuss how those activities are running in the past years and what the key issues of the program are. The paper also emphasizes participates (students and faculty) learning outcome in both technical aspect and culture aspect.

1. Introduction

Because of internet and www, the world shrinks. With the rapid technology development, globalization, and intensified competition, to make the business transition smooth, there is an urgent need for our engineers, engineering students, and instructors to have direct interaction with their international counterparts. A direct solution is for us to establish collaboration among faculties and students between U.S. and overseas partners.

We initiated and established an international collaboration with institution in China. This is one of the international programs that emphasizes on both research and educational aspects. This project started by the Prof. Jin's summer visit to Peking University (PKU), Beijing, China in 2006 which is supported by Wang Faculty Fellowship at Peking University in Beijing, China, 2006-2007 through California State University (CSU) International Programs, and then expanded to include several teams of Cal Poly students international visit from 2007 to 2012, which was also supported by Department of the Navy, under Award # ONR 6-N00014-07-1-1152 (2008) and Award # ONR 7-N000140811209 (2009); “ChunHui” exchange research fellow through Chinese Educational Department (2008), and NSF Grant OISE Award #1029135 from year 2010 to 2013, respectively. In summer 2009, Simeon Trieu, one of Prof. Jin’s graduate students, was awarded an NSF EAPSI summer and he also won the 1st place CSU research competition on graduate engineering and computer engineering level in 2010, because of working on the project. Now Prof. Jin is supported by 1) NSF Grant OISE Award #1029135 from year 2010 to 2013 and 2) Chinese National Key Research Lab Collaboration Grant 2010-2011 and 2011-2012. Those grants enable the Prof. Jin to bring more US students to work in China. Since 2012, our new goal is to let students in both countries to freely choose their research topics and their advisers. This paper will discuss how those activities are running in the past years and what the key issues of the program are. The paper also emphasizes participates (students and faculty) learning outcome in both technical aspect and culture aspect.

2. Project Activity

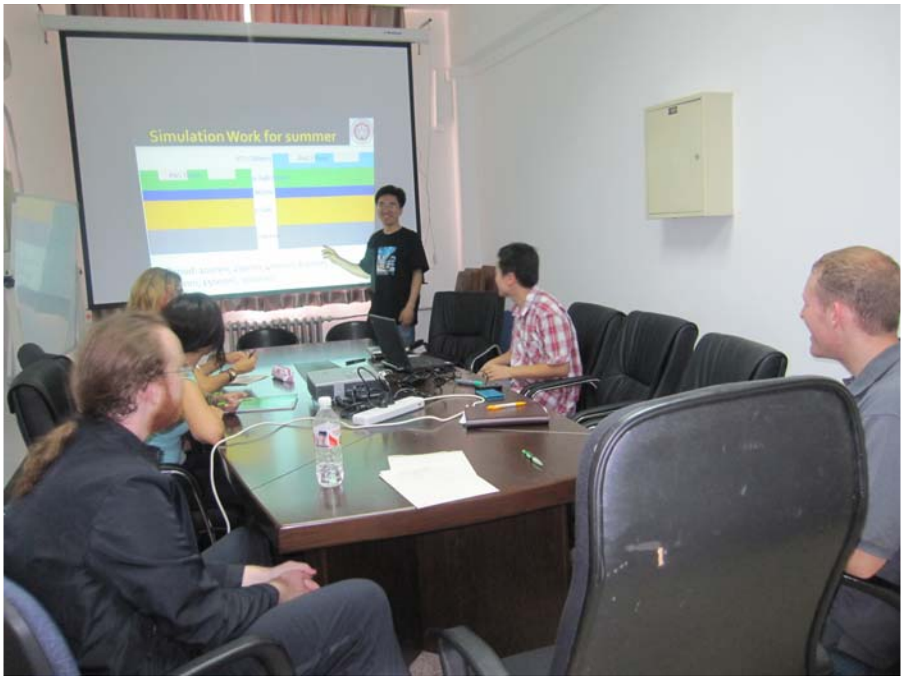
Cal Poly professors visit Peking University/Tsinghua University every summer to co-develop new LED structures since 2006. Our Cal Poly team is focus on design and validation, while Peking University/Tsinghua University is in charge of fabrication. Cal Poly provides and discusses LED design rules for China Partners. In the earlier years, our joint research team is very productive and brings a lot of publication in LD/LED development.

In summary, there are three stages of our activities:

1) From 2006 to 2008, we emphasized on faculty visits to establish a trust between the PI and Chinese partners, which was supported by Wang Faculty Fellowship through CSU International Programs (2006-2007); Department of the Navy, Office of Naval Research, under Award # ONR 6-N00014-07-1-1152 (2008) and Award # ONR 7-N000140811209 (2009); “ChunHui” exchange research fellow, Educational Department, China (2008), respectively.

2) Cal Poly students' summer visits to PKU (2009 - 2013) to enhance their graduated/undergraduate education, which is supported by NSF Grant: OISE Award #1029135 (2010 - 2013). Fig. 1(a) shows our students work at PKU and discuss simulation model for the devices with graduate students in Beijing China and Fig. 1(b) shows that Cal Poly and PKU students and faculty are working in the clean room. Fig. 2 shows Professor Bei Zhang from PKU visiting Cal Poly.

3) In 2012, we developed a Virtual International Research/Education Center on Energy Saving Light Emitting Diodes (LEDs) in Beijing.



(a)

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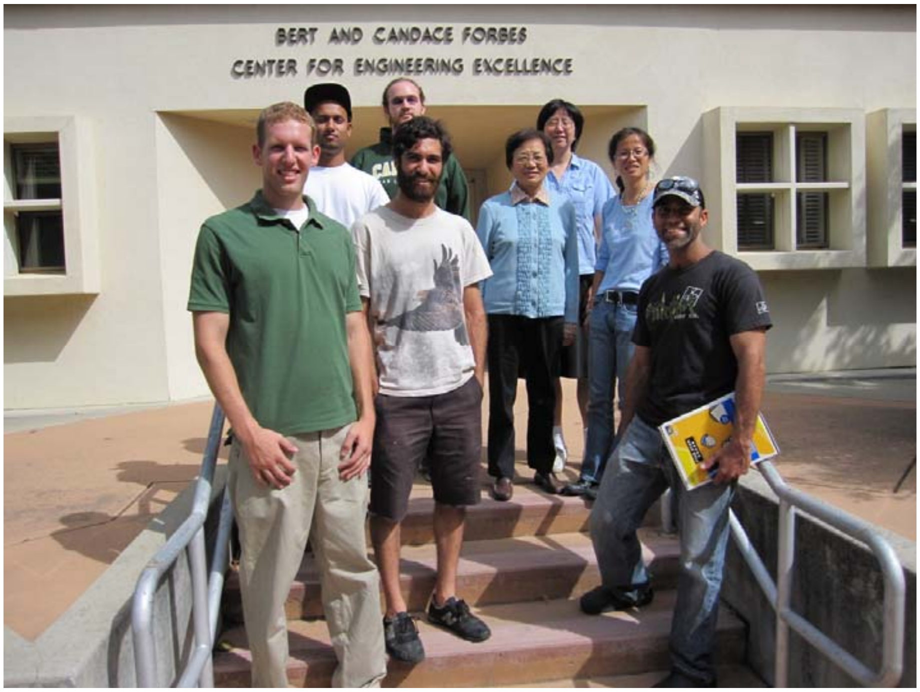
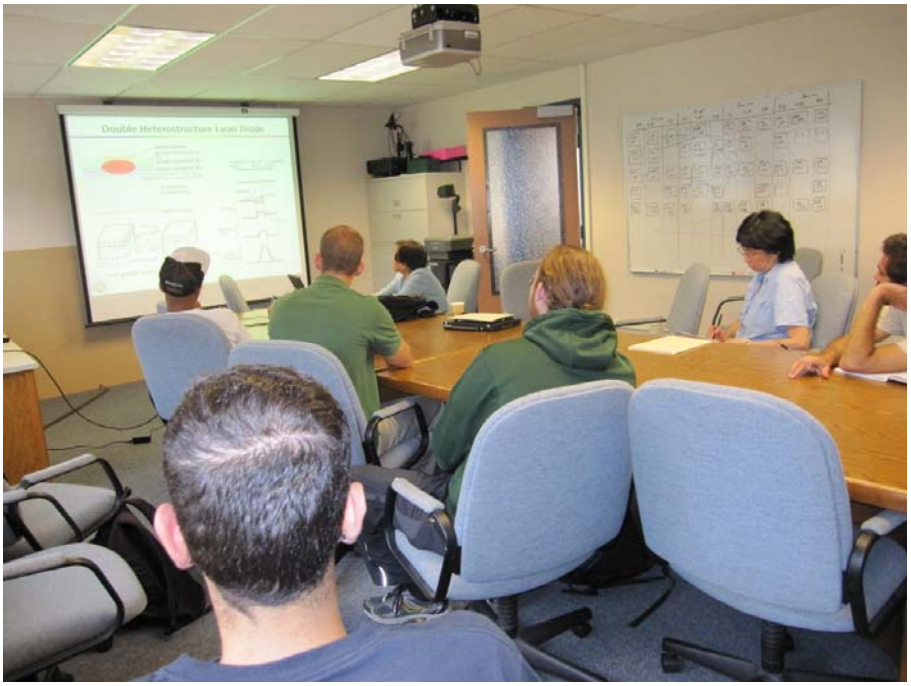
Fig. 1(a) Cal Poly students work at PKU and discuss simulation model with PKU graduate students in Beijing, China and (b) Cal Poly and PKU students and faculty are working in the clean room.



(a)



(b)

Fig. 2 Prof. Bei Zhang (a) from PKU visit Cal Poly in 2011 and (b) discuss GaN LD/LED reach with Cal Poly professors and students in San Luis Obispo, USA.

3. Description of Collaboration Teams

Peking University (PKU) founded in 1898 and was the first national comprehensive university in China. The Research Center of Wide Gap Semiconductor (RCWGS) of PKU is multidiscipline research center established in 2001. It is in the frontier of wide gap semiconductor research. ***Prof. GUOYI ZHANG*** is a professor in the School of Physics and Director of the Research Center for Wide-band Gap Semiconductors, Peking University, China. His research focuses on MOCVD techniques and GaN-based materials and devices. His recent research projects include GaN short wave length laser diodes, GaMnN dilute semiconductor, and polarized LEDs.

California Polytechnic State University (Cal Poly) is one of the 23 campuses making up the California State University system. Cal Poly is one of the largest undergraduate teaching institutes (non-PhD program) in USA and offers programs in engineering, science, business, and liberal arts. To prepare our students with the most advanced technology, most of our faculty is actively involved in advanced research, especially those in the college of engineering. The collaboration with PKU and Tsinghua University is certainly moving us one step further in that direction. ***Prof. Xiaomin Jin*** has strong photonic device measurement and simulation capability due to previous projects. She graduated fron Tsinghua University with B.E and MS in 1992 and 1996. And she received her Ph.D. from University of Illinois at Urbana-Champaign in 2001. Now she is an associate professor of EE department at Cal Poly. Overall she has twenty years of research experience in areas of photonics and fiber optic communication.

Cal Poly and PKU both have advantages in terms of facilities necessary for this project. The students at Cal Poly are strong in terms of employing different software models to perform simulations. The research group, led by Dr. Jin at Cal Poly, acquired several cutting-edge simulation packages over the past years, which made the detailed modeling and simulation possible. The group in PKU led by Prof. Zhang is strong in fabrication and characterization of LEDs. In fact, as well-funded research universities, PKU possesses advanced fabrication and characterization facilities that are not available at Cal Poly. The main fabrication center will still be in the Research Center of Wide Gap Semiconductor (RCWGS) of Peking University. The main simulation center will be located at Cal Poly, USA.

4. Technical work and Collaboration

In this section, we use GaN LD/LED research as examples for detail technical collaboration. With the demand to develop energy efficient, bright, and green light sources, intensive research efforts have been made on the studies of light emitting diodes (LEDs). LEDs can be used in many applications, such as solid state lighting, photonics, display technology, and machine vision. To meet the needs of these applications, light sources must be able to achieve high luminosity with minimal amount of heat generated at low power. The key limitation for light emissive devices is the light trapping due to the device layers' low critical angle. The majority of the light generated has few angles of escape and is reflected back within the device instead of escaping. The solution of above problem is the following: the emission surface can be patterned with a transmission diffraction grating that allows more angles of escape via Bragg diffraction. Incident light at the surface would be scattered at the emission surface instead of being simply transmitted or reflected. In addition, it has been shown that the same patterning can also apply to the Ag reflector plate, commonly used to reflect the light escaping at the bottom of the device towards the top emission surface [1], [2]. The second device inefficiency is due to absorption by defects in the GaN crystal or by the highly absorbent multiple quantum well layers that light waves must eventually pass through if reflected at the emission surface. When light encounters a defect or the quantum well layers, it will be absorbed instead of being transmitted at the surface. This is a critical aspect of light extraction efficiency, not only because the photon cannot escape the device, and therefore cannot add to device luminosity, but also because the absorbed photon transfers its optical energy into a phonon or lattice vibration, thereby generating heat within the semiconductor. So, it is critical that photons are extracted in greater quantity and speed before recombination occurs [3], [4]. A diffraction grating will again relieve this issue via Bragg diffraction.

The device model is a key issue in opto-electronic device research. Grating structures can be patterned with many shapes including: pyramidal, spherical, conical, cylindrical, and so on, but only a few can be feasibly fabricated with great success. It is very expensive to fabricate different photonic devices and make direct comparisons. We first fabricate some basic devices and test them (performed at Peking University or PKU). Then, we use the experimental data and create device models which match the experimental data. We then vary the device structure in our model and find the optimized design for the photonic device and provide feedback to PKU. The device model will allow intelligent device selection, modification, and optimization of device design/performance.

At beginning, in 2006, Prof. Jin used a simple rigorous couple wave analysis (RCWA) analytical method to study top grating structure, which was published in [5, 6]. RCWA can only simulate periodic grating structures at one interface and cannot study grating performance inside devices. In summer 2008, Dr. Jin visited PKU to improve the project and decided to use the Finite Difference Time Domain (FDTD) method for this grating study, which in principle can simulate any grating structure and its effects on LED light extraction. Prof. Jin first developed the FDTD single reflection grating study. The transmission top grating simulation results were summarized and published. Her current research is focus on top, bottom, and top-bottom grating simulation for maximum light extraction efficiency of GaN LEDs using the FDTD method. The FDTD reflection grating simulation was compared to and agreed with experimental data provided by Peking University [7] [8]. The top-bottom (or transmission-reflection) grating results are also studied. This direct comparison of 181 different combined top-bottom grating cases using the FDTD method is presented for the first time [9]. Etching a structure on the extraction surface and/or on the bottom reflection surface commonly solves the light trapping issue. The single grating simulation has been studied intensively already. However, it is novel to present effects of top gratings, bottom gratings, and combinations of both using FDTD theory. It is also not practical to fabricate all the grating cases and obtain the optimization rules and trends. Even our calculation here is only limited to one particular GaN LED structure developed by PKU [7, 10]. Moreover, in fabrication, etching involves defects; the grating structure is not a perfectly periodic crystal. Finally, transmission-reflection error grating models are also presented. Randomization in grating design and its effects in fabrication are also presented for the first time [9]. We develop an error grating model to study the effects of the fabrication randomization. We published 1st paper on the error grating model of the top-bottom grating structures. In the last two years, we intensively study top, bottom, and top-bottom nano-grating simulation for maximum light extraction efficiency from Gallium nitride (GaN) LEDs using the Finite Difference Time Domain (FDTD) method [11][12][13].

5. Outcome

The work distribution between U.S. students and Chinese students was clear, yet closely related. US students focused on device simulation, and Chinese students worked on GaN device fabrication. Exchanging results was necessary for progress on both sides, which encouraged them to actively communicate with each other. The result of this collaboration was successful from both a research and education point of view. We published more than 15 technical papers in the past years. Student comments on both sides confirm that they obtained a better understanding about foreign cultures and that they thought it was helpful for them if they chose to pursue a career in a multinational firm.

There are a lot of key elements or advantages of the projects. Here we list some of those [14]:

- **Trust Building/Global Friendship:** The leaders of the project should have trust and understanding. The students in both countries are also building up their friendship. One of US students even find Chinese wife.
- **Regular communication and teamwork:** Frequently holding teleconferences with the entire group (including both U.S. and Chinese teams) is important for both students and faculty to connect with each other, not only on technical issues, but also on working habits and culture differences.
- **Management skill:** The management skill of the professors from both sides is critical throughout the project. Research work needs to be distributed based on each party's strength. In our case, Cal Poly possesses an advanced design environment, and PKU has cutting-edge fabrication clean rooms. Therefore, Cal Poly is in charge of design validation and improvements, while PKU is in charge of design realization and testing.
- **Mutually beneficial topics:** This is an important motivation for the project. Good research topics and project goals should be carefully selected by professors from both sides. Complementary capabilities of both sides will produce mutual benefits for the research and strengthen collaboration in the future.
- **Financial independence:** It is difficult to receive funding from other countries. We decided to fund research independently. We are in charge of software development funding, and PKU funds their fabrication facility. As for the research visits, the sending country pays the international airfare, while the host country pays for the expenses related to a short visit.
- **Low financial burden on the students from both sides:** For some students, spending a period abroad is costly. Students also have to plan carefully to make their curriculum flexible enough to allow them to be away long term and not fall behind in other courses. Our project allows the students to get international experience without having to deal with interruptions in their regular course sequence. The short international visit is only an option and enhancement of the collaboration, but it is not a necessary component.
- **Data accessibility around the world (spontaneous global communities):** The development of computers, the Internet, the World Wide Web (WWW), and fiber optical communication systems transforms international research and education into a global scientific enterprise. The current technology allows the formation of spontaneous, international learning communities. We can share information in textual, graphic, and multimedia formats across the

world. This shrinking world provides our students a low-cost international education environment. It can be called “Spontaneous global communities.”

- **The consciousness of foreign countries:** The consciousness of foreign countries is improved throughout the project, which also improves U.S. students’ global understanding.
- **International co-authorship for the research results:** This is an important outcome of the international educational and research partnerships.
- **English/Chinese learning community:** English is the basic language for communication. However, U.S. students are also interested in learning a little Chinese besides research. Chinese students are also offered an unusual learning opportunity of presenting and defending their projects using technical English terminology. Students from both sides are working toward eliminating the linguistic barrier.

6. Conclusion

Previously, because of the lack of communication, international professional groups working on similar research projects did not exchange ideas before publishing their research results. Therefore, some of the research was developed redundantly, which wasted resources. The development of telecommunication in the past decade opened unprecedented opportunities for international scholars. Researchers, leading student-scholar teams around the world, can use each other’s knowledge and work together on a project in a timely fashion, leading to what we call international research and education collaboration. However, there are no universal models for international collaboration. Each case has a unique character. In our project, researchers in Cal Poly and PKU are involved in these activities. Communication between faculty advisors and students on all sides is important to the success of this project. We also hold annual meeting for the collaboration to exchange ideas both on research and culture.

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