International Engineering Research and Educational Collaboration on Gallium-Nitride (GaN) Lasers and Light Emitting Diodes (LEDs)

Xiaomin Jin[1], Bei Zhang[2], Fei Wang[3], Jason Flickinger[1], Sean Jobe[1], Tao Dai[2], Guoyi Zhang[2]

1. Electrical Engineering Department, California Polytechnic State University, San Luis Obispo, xjin@capoly.edu
2. School of Physics, Peking University, Beijing, China, beiz@water.pku.edu.cn
3. Electrical Engineering Department, California State University at Long Beach, Long Beach, fwang@csulb.edu

Abstract

Nowadays cost reduction is the top priority for most US companies to survive. To reduce operational cost, many companies chose to outsource their manufacturing divisions as well as R&D divisions to Asia, most notably China. Therefore, there is an urgent need for US engineers who are able to make a liaison between US headquarters and subdivisions in China. US institutions should be aware of this trend and prepare engineering students for that.

We established a long-term International Engineering Education and Research Collaboration Program between California Polytechnic State University (Cal Poly), USA and Peking University (PKU), Beijing, China on GaN light emitter research in the past three years. We focus on GaN laser diode (LD) research for the first year. GaN Light emitting diode (LED) research was added during the second year. The project begins by having faculty members working in PKU for one summer. The collaboration for the rest of the period was done through tele-conference and emails. Cal Poly graduate students are grouped with graduate students in PKU and worked closely on certain projects. Through this project, our students obtained experience of collaborating with foreign partners, especially awareness of culture difference, without going to aboard. Their work assignments are clear, yet closely related. Our students focus on device simulation and foreign students work on GaN device fabrication. Exchanging results is necessary for the progress on both sides, which encourage them to actively communicate with each other. The result of this collaboration is successful from both research and education point of view. We published four technical papers on GaN-laser research in the past year. Student comments on both sides confirm that they obtain better understanding about foreign cultures and they think it is helpful for them to pursue a career in a multinational firm.

1. Motivation

Nowadays, A new set of challenge faces both United State industry and educational institutions [1-2]. Because of rapid technology development, competition among companies is now globalized and intensified. In order to succeed, a company must manage to face these competitions. Cost reduction is always the first priority for most companies to survive. To reduce operational cost, many US companies have already moved part of their manufacturing and R&D centers overseas, and they plan to continue the out-sourcing process. Southeast Asia, most notably China, is among the top choices for US out-sourcing because of its fast developing speed, boosting economy and well-educated engineering work force. To make this business transition smooth, there is an urgent need for our engineers, engineering students, and instructors to have direct interaction with their international counterparts [3]. It has been noticed by industries, governments, and institutions that our university graduates in US are inadequately prepared for the challenges brought by industrial globalization. Therefore, we are obligated to introduce this globalization trend to our students and provide necessary training for them to successfully compete in this environment. A direct solution is for us to establish collaboration among faculties and students between US and oversea partners.

In supplement to the study-aboard program that has been offered for years in Cal Poly, we initiated a collaborative research/education program with institutions in China. This is the one of the international programs in Cal Poly that focuses on both research and educational aspects. Our international partner is School of Physics, Peking University in Beijing, China. The goals of this program are:

- Improve student's ability to work in a multi-culture environment;
- Improve student's critical thinking and independency by involving them in an open-ended research project;
- Improve student's technical competency by letting them work on cutting-edge research topics.

The major objectives of this cooperative research project are:

- Establish long term collaborative research relationship in form of telecommunication, instructors exchange and students' exchange.
- Establish routine but powerful simulation, fabrication and characterization methods;
- Optimize design to achieve high performances of photonic lattice-based Gallium-Nitride epitaxial materials and optoelectronic devices.

2. Introduction of PKU and Cal Poly

Peking University (PKU) is one of the most prestigious higher education institutions in China. The university is a research oriented institution that is ranked No. 1 in almost all ranking systems in China. PKU is located in northwestern side of Beijing, where universities, high-tech companies and international corporations accumulate. The university currently has three campuses and offers programs in science, engineering, business, liberal arts, law and medication. The university is one the first two schools in China that are funded by China's strategic development plan in science, technology and

engineering. PKU has 110 years of history and has a long tradition in international collaboration. Fluency in English is a requirement for both undergraduate and graduate students in PKU. This removes the language obstacles for this collaboration.

California Polytechnic State University (Cal Poly) is one of the 23 campuses making up the California State University system. Cal Poly offers programs in engineering, science, business and liberal arts, of which college of engineering is the largest college across campus. Cal Poly offers bachelor and master degrees and is categorized as teaching oriented institutions. However, in order to prepare our students with the most advanced technology, most of our faculties are actively involved in advanced researches, especially those in college of engineering. This collaboration with PKU is certainly moving us one step further in that direction. In Electrical Engineering department, an individual design/research project is required for BS degree and a thesis project is required for MS degree. Students that are involved in this research collaboration include both undergraduate and graduate students.

3. Technical Merit and Research Plan

Recently, many efforts were made on the research of Gallium-Nitride (GaN)-based optoelectronic semiconductor devices, due to their vast promising applications, such as solid state light sources, and ultraviolet light emitters for high-temperature electronics [4,5]. In some applications, they become even irreplaceable. However, GaN-based semiconductors have totally different optical and electrical properties when compared to other materials [6-9]. Researchers can make light emitters, such as laser diode/light emitting diode (LD/LED) out of GaN-based semiconductors, but the mechanism for their operation has not been fully understood yet. This research covers several fundamental issues of GaN-based LED/LDs including 1) the study of device surface structures that closely associates with light extraction; 2) the investigation of the effects that influence the power transition efficiency.

For the technical content of this project, a five years research plan has been laid out. In the first year, we investigated the optical transverse-mode distribution in the GaN LDs, and their basic lasing characteristic. In the second year, we are studying the application of nano-photonic structure (photonic lattice or photonic crystal) in design of GaN devices. At the same time, we are evaluating and comparing the confinement factor of the gain models in various GaN device structures, and optimizing the anti-guide layer design. In the next three years, we will optimize the structure to design high power lasers or LEDs, define some design rules for GaN-based opto-electronic devices, and reveal some of their underlining physics.

Cal Poly and PKU both have advantages and disadvantages in term of facilities necessary for this project. The students at Cal Poly are strong in term of employing different software models to perform simulations. The research group lead by Dr. Jin at Cal Poly acquired several cutting-edge simulation packages over these years, which make the detailed modeling and simulation possible. The group in PKU lead by Prof. Bei Zhang is strong in fabrication and characterization. In fact, as a well-funded research university,

PKU possesses the most advanced fabrication and characterization facilities that are not available in Cal Poly. Therefore, the student in PKU will prepare some characteristic tests of the GaN-based photonic-lattice structures. These photonic lattice structures become more and more important in the GaN-based optoelectronic devices.

4. Project Outline

The collaboration started by initial meeting between research groups in PKU and Cal Poly. Dr. Jin represented Cal Poly visited the research labs in Peking during summer of 2006 (sponsored by Wang's Faculty Fellowship). The innovative idea of this project is that we can have students experience international education training without going aboard, which is less expensive for both groups of students. Research collaboration and communication could be done remotely using internet and tele-conferences. This idea has worked very well. Some of the key elements of this collaboration are:

- Professors from both sides should be the leaders of the project.
- The project needs to be mutual beneficial, and supported with complementary capabilities.
- At the beginning, the faculty needs to work at the international institution for a sufficient period of time to demonstrate US research capabilities and to gain the trust of each others.
- Because of the current communication technology, phone conference calls, the internet, and email can be used to facilitate a productive research relationship.
- We build one-to-one student relationship. The first year, a Master student from Cal Poly partnered with one PhD student in PKU.
- We build "student-mentor" relationships focusing on the research topic.
- Each year, we will focus on different tasks on GaN LED and GaN LD development.

5. Detailed Activities

To obtain necessary research skills for this international project, Cal Poly students need to take EE403/443 (Fiber Optic Communication and Laboratory), EE418/458 (Photonic Engineering and Laboratory), EE335/375 (Electromagnetic Fields and Transmission and Laboratory), EE402 (Electromagnetic Waves), EE524 course (Solid State Electronics). Waveguide and photonic devices concepts are address in those courses. Basic training through senior design project is provided to students before they get involved.

A 1D GaN LD simulation models for design optimization (Figure 1) was developed during the initial visit to China. This model reasonably considered the optical fields in the devices. However, this model has not included the lasing action simulation. Therefore, the project activities in the first year of collaboration were: 1) to improve the 1D model, 2) to develop a 2D model GaN LD model, and 3) comparison of the enhanced 1D model and 2D results. Three Cal Poly students and two students in PKU are involved in these activities. Communication between faculty advisors and students on both side are key to the success of this project. As mentioned earlier, students in Cal Poly are in charge of model development. The initial results are transferred to students in PKU, which provide

guidance for their fabrication and characterization of the devices. Characterization results are transferred back to Cal Poly site, where students at Cal Poly improve the model based on the physical data. Figure 2 shows the flow chart of the student-mentor (two-level) communication between the two institutions on the research topics. The final results are the device designs.

Phase One: The GaN-based laser diodes (LDs) have attracted a lot of attention as short wavelength light sources in recent years. However, high threshold current and short lifetimes are the main problems in these lasers. One of the major reasons for these drawbacks is the anti-guided-like behavior of waveguide mode associated with the n-GaN buffer layer. Cal Poly group has calculated the transverse mode distribution of InGaN/GaN laser diodes, which was demonstrated at PKU. We find that the n-GaN buffer thickness is an important parameter in the lasing-mode design, and point out that the maximum optical-confinement-factor variation is due to transverse mode coupling. Our calculation also proves that the current design is very close to an optimal design, but still has more room to increase the optical confinement factor, in order to reduce the lasing threshold, and to further improve laser performance, such as lifetime and far-field patterns. We published four papers Ref [10-13] on this research topic.

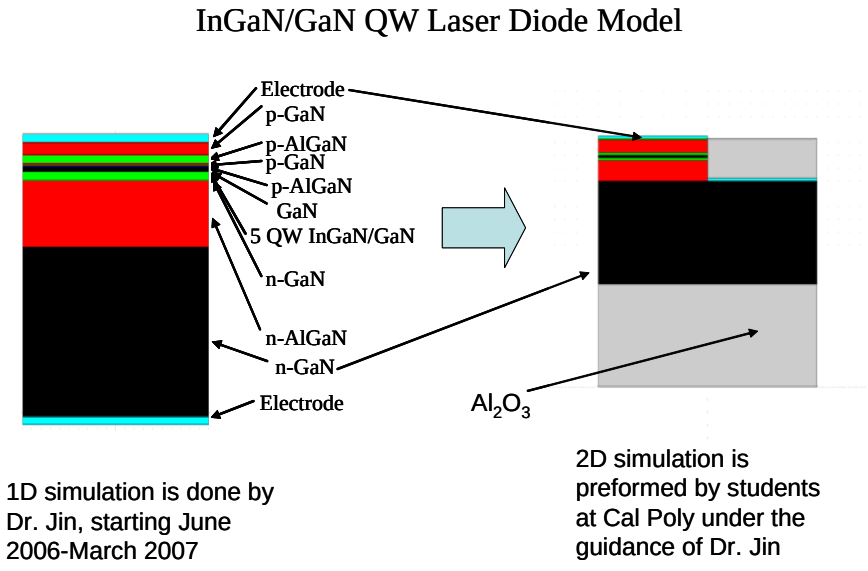

Figure 1 The GaN Quantum-Well device simulation research

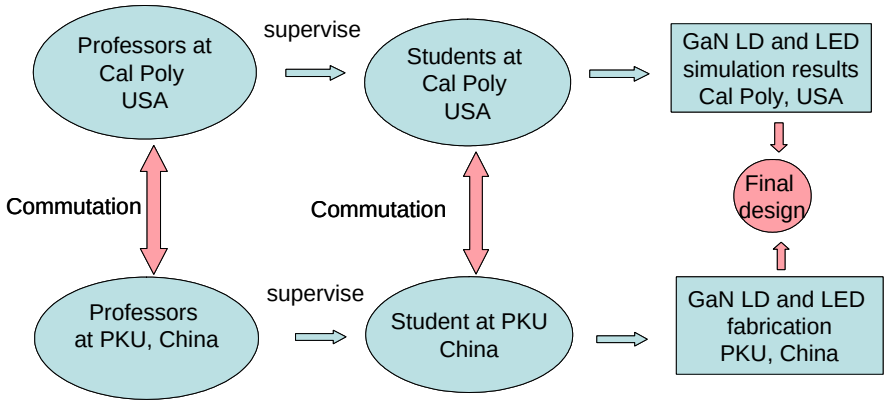

Figure 2 The joint research team at Peking University and California Polytechnic State University with the two-level communications

Phase Two: Advancements in GaN-based LED technologies have been growing fast too. But a common problem still exists in conventional LEDs. Photons are trapped in the device and limit the amount of light extracted. Photonic lattices are one of the proposed solutions of the problem. Photonic lattices are complex arrays of microstructures in a solid dielectric material that can control and radically influence the propagation of light in different directions. They represent a new engineering discipline, combining the principles of electromagnetism with the concepts of solid state physics. Photonic lattices have numerous applications in optics and optoelectronics in particular to GaN-based LEDs. The second phase of collaboration concentrates on the simulation, design, and characterization of the GaN-based photonic lattices and related devices. The impact of the behavior on photonic lattices of pillars or holes with different symmetries, periods on the performances of GaN-based light emitters will be mainly calculated at Cal Poly. Approximately 6-8 more undergraduate and graduate students are involved into this project. A variety of photonic lattice structured on GaN-based light emitters will be fabricated at PKU by different methods, such as ion beam lithography, FIB, ICP dry etching and nano-imprint technique etc. Some of the characteristics of the structures and devices will be measured by both groups.

6. Results

In July 2007, a formal collaboration contract has been signed by professors from both sides indicating their agreement for a long-term collaboration for the next 4 years until August 2011. The result of this collaboration is successful from both research and education point of view. From research point of view, the collaboration combined the strength of Cal Poly and PKU. As a clear indicator of technical successfulness, we co-published four technical papers on GaN-laser research in the past year. To assess the outcome of educational merit of this project, we collected comments and suggestions from students. Student comments on both sides confirm that they obtain better understanding about foreign cultures and they think it is helpful for them to pursue a career in a multinational firm. Up till now, six students who involved in this project finished their degree, among which two students graduated and working at companies, 4

students pursued graduate study. All students commented that their experience of multi-culture research helped them in the job interview with large corporations. The open-ended research project gives students opportunity to act as an investigator, while instructors serve as facilitator. All students comment that their critical thinking skills are improved and they are more confident now to work independently.

7. Key elements of the international research collaboration

Previously, because of the lack of communications, international professional groups working on the similar research projects didn't exchange ideas before the publication of their research results. Therefore some of the research was developed redundantly, which wasted the resources of society. The development of telecommunication in the past decade opens unprecedented opportunities for international scholars. The researchers, leading student-scholar teams around the world, can use each others' knowledge and work together on a project in timely fashion, leading to what we call international research and education collaboration. However, there are no universal models for the international collaboration. Each case has its unique character. In our project, the key elements and obstacles of building the international research collaboration are discussed below; some of those items are closely related to each others:

- ***"Trust":*** The leaders of the project should have trust and understanding. This is the first and the most important aspect. Even with the traditional international partnerships, "Trust" is still required for effective international collaboration. In earlier 2006, we started talking about this project. After the first year of work, in July 2007, we signed the collaboration contract for the next four years.
- ***Regular communication and teamwork:*** The first year is very critical to set the foundation for the future collaboration. Each team leader needs to response very fast to the requests of the other side. Frequently holding tele-conferences of entire group (including both US and foreign teams) has paramount importance for both students and faculty to get connection with each other, not only on technical issues, but also on working habits and culture differences. Regular communication is also essential to build the trust bond.
- ***Management skill***: The management skill of the professors from both sides is very critical throughout the project. Research work needs to be distributed based on each party's strength. In our case, Cal Poly possesses 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.
- ***Research element:*** Another important purpose for this project is to team-up our students (undergraduate teaching university) with a foreign research university, and be exposed to advanced research topic.
- ***The student-mentor team and two-level communications:*** The direct discussion between foreign and US students served as important agents for inserting an international dimension to the research effort. However, the discussion between the students should be supervised by professors to control the technical aspects of the

projects. The students from both sides also need to present their work to each other, and to the two groups of professors for discussions.

- ***Mutually beneficial topics:*** This is an important motivation for the project. Good research topics and project goals should be carefully selected by the 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 very difficult to apply funding from the other country. We decided to fund research independently. We are in charge of software development funding. Peking University in China will fund their fabrication facility. As for the research visits, the sending country pays the international air fares, the host country pays for the expenses related to short visit.
- ***Low financial burden on the students from both-side:*** For students, spending a period aboard is very costly. Students also have to plan carefully to make their curriculum flexible enough to allow them to be away for a long term and not fall behind in other courses. Our project allows the students to get some 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, not a necessary component.
- ***The foreign-born US scientists:*** The international research bridge is built up by international students from China, or so called the foreign-born US scientists and engineers. The foreign-born US scientists are the greatest asset in promoting international collaboration. We need to recognize international talent which lies at the center of the cultural diversity needed for the global environment.
- ***Data accessibility around the world*** (***Spontaneous global communities):*** The development of computers, internet, World Wide Web (WWW), and fiber optical communication system transforms the international research and education into a global scientific enterprise. The current technology allows the formation of spontaneous international learning communities. We can share the information, such as textual, graphic, and multimedia format across the world. This shrinking world provides our students a very low cost international education environment. It is can be called "Spontaneous global communities".
- ***The consciousness of foreign countries:*** The consciousness of foreign countries is improved throughout the project, which also improve US students' global understanding.
- ***International co-authorship for the research results:*** This is an important outcome of the international educational and research partnerships.
- ***Annual visit:*** Any level of annual visits benefits the international research project.
- ***English:*** English is the basic language for communication. However, US students are also very interested in learning a little Chinese besides research in GaN LDs and LEDs. Chinese students are offered an unusual learning opportunity of presenting and defending their projects using technical English terminology. Students from both sides are working towards eliminating the linguistic barrier.

In general, this project builds an international virtual research laboratory, which develops and enhances students' awareness of humanity and the world around them. The future

implementation of the international projects will depend on growth and sustenance of these relationships.

8. Future Work

This collaboration is well established. We are keeping it rolling and move it to the higher level. In the summer 2008, Dr. Jin will be a visiting professor at PKU supported by "ChunHui" exchange research fellow, Educational Department, Chinese government to promote further interconnection.

In the long run, the participants of both sides will exchange visitors during the period of this project. Faculties in US will visit PKU to discuss and adjust each year's research topics in the summer. The participants of PKU group will bring some of the samples to Cal Poly to perform characterizations at appropriate times.

In summary, Cal Poly's milestones for the next few years on the international research and education are:

- Students from the two universities will make presentations to each other through internet.
- Involvement of undergraduate students in the research, which will be a challenge because of the short period of time available for undergraduates.
- Seek funding to send students to China in future summers to really immerse them in international environment.
- Seek research projects with research laboratories of US or China companies. Some initial contacts have been made between Cal Poly and some globalized corporations, such as Agilent Technologies. Although there are more hurdles in the University-Industry research collaboration, such as Intellectual Property (IP), both parties still believe a mutual beneficial agreement is possible.

9. Conclusion

We established a long term International Education and Research Collaboration Program (IERCP), which can be a model for other universities. The model started by faculty visiting and expanded to international students' team-up and collaboration. With awareness of current technology development trends, we established a joint research program, and are developing international educational activities. This collaboration helps our students adapting themselves to a globalized environment and simultaneously promotes advances in science and technology by involving in cutting-edge GaN LED research. In summary, the result of this collaboration is successful from both research and education point of view. We published four technical papers on GaN-laser research in the past year. Student comments on both sides confirm that they obtain better understanding about foreign cultures and they think it is helpful for them to pursue a career in a multinational firm.

Acknowledgments

This project is supported by the Wang Faculty Fellowship 2006-2007 through California State University (CSU) International Programs USA; Department of the Navy, Office of Naval Research, under Award # N00014-07-1-1152, USA; “ChunHui” exchange research fellow 2008, Educational Department, China; 973 program-National Basic Research Program of China (2007CB307004); High Technology program (863-2006AA03A113) and National Nature Science Foundation of China (60276034, 60577030 and 60607003).

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Biographical Information

Dr. XIAOMIN JIN: received her Ph.D from Univ. of Illinois, Urbana-Champion in 2001. She has worked in the research laboratories at Corning Lasertron Inc, W. L. Gore and associates, and Optical Communication Products, Inc. Now she is an assistant professor at California Polytechnic State University. Her research focuses on fiber optical communication and optoelectronic devices.

Dr. BEI ZHANG: is a professor of Physics in School of Physics, Peking University. She graduated from Department of Physics, Peking University in 1962. Recently her research is focused on the photonic lattices based GaN system light emitting devices (laser diode and LEDs).

Dr. FEI WANG: received her Ph.D from Univ. of Cincinnati in 2005. She joined California Polytechnic State University as an assistant professor in 2005. Now she is an assistant professor in California State University, Long Beach. Her research focuses on electronic materials and devices.

Dr. GUOYI ZHANG: is a professor of School of Physics and Director of 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 LED.