

Investigating THz Optoelectronic Devices

Tiffany Ko¹, Richard Green², David Barate², Ji-hua Xu², Aji Annapara², and Alessandro Tredicucci²

¹ *Princeton University, Engineering Research Center on Mid-Infrared Technologies for Health and the Environment (MIRTHE), Princeton, NJ 08544, USA. E-mail: tko@princeton.edu*

² *Scuola Normale Superiore, National Enterprise for nanoScience and nanoTechnology (NEST), 56126 Pisa, PI, Italy*

ABSTRACT:

Tiffany Ko, an Electrical Engineering undergraduate student at Princeton University traveled to the host institution Scuola Normale Superiore in Pisa, Italy. During her three month visit, she investigated various THz optoelectronic materials and device. She gained in-depth experience with new experimental equipment and techniques, greatly applicable to future work. Her visit was also very regionally and culturally educational. Without any previous exposure to European culture, Ko gained a new international perspective. As an Asian-American female, she added diversity to both the Italian community and predominantly male workplace. Consequently, she was also able to both share and learn from her colleagues in several aspects. In sum, the international travel was a rich educational experience that fostered strong international relationships and additional future collaborations.

INTRODUCTION

International travel and research abroad allows an individual to gain not only a different academic and scientific perspective, but also experience a paradigm shift in a different work environment within a different culture. This is especially rewarding early in one's career.

The traveler, Tiffany Ko, is an undergraduate student currently in her junior year at the awardee institution, Princeton University. She is working towards a Bachelor's in Electrical Engineering with certificates (minors) in Engineering Biology and Material Science. Prior to travel, she conducted research at Princeton University under Professor Claire Gmachl involving mid-infrared materials and devices with a strong focus in mid-IR quantum cascade (QC) lasers.

The international exchange, which occurred from June 1st – August 27th 2007, provided the student with an internship at a research facility on the campus of the Scuola Normale Superiore di Pisa, a prestigious international university located in Pisa, Italy. The research facility is funded by the National Enterprise for nanoScience and nanoTechnology (NEST) organization. The principle scientist whom Ko worked under is Dr. Alessandro Tredicucci. Dr. Tredicucci's group is well known for their research in THz optoelectronic devices. In this regard, the anticipated research topic, THz optoelectronics, was a nice extension from the student's previous experience and interest.

As such, the goals of the collaboration were to allow the student a unique immersion opportunity in a different culture and working environment. Investigation and research experience in a different regime of optical devices would broaden the student's technological knowledge base. In addition, by working in a different experimental lab, there would be opportunity to learn new and different experimental techniques. With a biological knowledge base, the student was equipped to contribute towards an ongoing biological spectroscopy research effort in the host laboratory. The host lab would also benefit from the new perspective of a student with previous work experience in a similar experimental lab.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

There was a broad range of research opportunities available at the hosting laboratory. Working under lead scientist Dr. Alessandro Tredicucci were one researching scientist, three post-docs, three doctorate students, and two undergraduate students. Research topics, all mostly pertaining to the optical THz regime, ranged from quantum cascade lasers to cavity-enhanced polariton emitters. Ko worked on several projects: autonomous control of LIV characterization measurements for THz quantum cascade lasers, THz QC laser design, THz light generation using a non-linear THz QC laser medium, THz absorption of CdSe nanorods, and bleaching of cavity polaritons.

From previous research experience under Prof. Gmachl, the student had acquired an aptitude in LabVIEW programming, a language used primarily for remote control of experimental equipment used for signal generation and measurement/analysis. Utilizing this, she designed and executed a program (Fig. 1) which enabled the host lab to remotely set parameters and autonomously run Light-Current-Voltage (LIV) characterization measurements on THz QC lasers. This program was similar in many respects to a program previously written and designed for characterizing the shorter wavelength mid-infrared QC lasers utilized at MIRTHE. While working on this project, Ko interacted with many members of the host laboratory, incorporating suggestions and requests.

Next, focus was turned to THz non-linear light generation using a THz QC laser as a non-linear medium. This device was designed, grown, and sent from the lab of Carlo Sirtori, a collaborating group located at the University of Paris. Previous work has shown this THz QC laser capable of mapping its normal THz emission onto an injected near-infrared

(NIR) beam using difference frequency generated sidebands (Fig.2) [1]. Thus, there was interest in investigating if non-linear THz light could be generated when a broadband NIR source, centered on the original injected NIR frequency, but also containing the two known sideband frequencies were injected. Because the conversion efficiency was low, in order to generate some measurable amount of light, a high-power ultrafast NIR laser source was used. Primarily working with post-doc Richard Green, but also scientist Jihua Xu who was in charge of the ultrafast laser, Ko designed, setup, and performed measurements by aligning the ultrafast NIR beam, the THz QC laser, and a broadband, fast-response pyroelectric averaging optical power detector (Fig. 3). Unfortunately, the power of the injection laser damaged the sample and no results were obtained. However, similar non-linear media are under investigation at MIRTHE and the new knowledge and experimental techniques learned by the student are potentially useful in future research at MIRTHE.

The next endeavor involved measuring the THz absorbance of CdSe nanorods as a function of incident visible light. The absorption lines of the CdSe nanorods fall in the visible wavelengths, thus by increasing the magnitude of incident white light, the population of excitons should increase, changing the THz absorption. Once analyzed, the measured changes in THz absorption magnitude and frequency would give great insight into the electrical properties and physical consistency of the nanorods. The nanorods were sent from collaborators in another national lab and designed and fabricated as per [2]. With the assistance of post-doc David Barate and doctorate student Aji Annapara, scanning electron microscope (SEM) imagery (Fig. 4) was taken and absorption measurements were setup using a Fourier-transform infrared spectrometer (FTIR) equipped with a room-temperature, THz DTGS detector. The measurements were inconclusive due to significant noise to signal ratio. Equipment failure prevented further investigation. However, the student learned valuable measurement techniques and specialized knowledge concerning the operation of the FTIR, a commonly used device in analysis in MIRTHE labs and experimental photonics in general.

Near the end of her stay, the student began another project with Annapara regarding his work with polaritons in intersubband microcavities. Ko's visit proved to be a rich intellectual experience. She was able to work with several new optoelectronic materials and devices which involved learning additional fundamental knowledge, in-depth operation of instrumentation, and applicable measurement techniques, all of which contributed to her growth as a student and researcher. In turn, she was able to contribute a new perspective and apply her own expertise to assist the members of the NEST research group.

BROADER IMPACTS OF THE INTERNATIONAL TRAVEL

Prior to the international travel supported by the supplemental award, Ko, a U.S.-born Asian-American citizen, had never travelled to Europe. This was her first international work experience. Many of the host laboratory researchers were internationals themselves, nationalities including Greek, Spanish, Swiss, British, Chinese, and Indian. Though there was a female lead scientist within the NEST administration, of the research

staff and students only a very small portion were female. Thus Ko brought both multi-national and gender diversity to the workplace.

Additionally, for the first two months, Ko took residence in a university dormitory. Granted the international prestige of the university, she was able to meet top-tier students from all over the world who received full-funded education, room, and board through the university. These included individuals of German, French, Dutch, Spanish, and Armenian nationality. On a day-to-day basis, she conversed with students of varying cultures and backgrounds. During downtime, she took the opportunity to travel and/or experience surrounding cultural events and venues.

Though initially she had very little grasp of the Italian language, by the end of the 3-month residence in Pisa, Italy, she was able to converse at a basic dialogue level with local residents and near fluently listen and read. By reading the local and national papers in order to improve Italian fluency and talking with colleagues on various topics ranging from music to the judicial system, Ko gained exposure to several new perspectives pertaining to politics and social values placed within the context of a very different Italian culture.

Further collaboration between Princeton University and the SNS NEST laboratory is encouraged through the additional relationships created. Ko's visit spread the word of MIRTHE's purpose and goals to those who were unfamiliar with the organization and informed those who were unaware of the opportunity of future academic exchange. Every individual with whom Ko interacted learned about her research work and background. In such a way, she increased both the international awareness of MIRTHE and the potential for future international collaboration.

DISCUSSION AND SUMMARY

For early career researchers, an international internship abroad is an opportunity of a lifetime. For Ko, who had never travelled to and experienced the culture of Europe, a three month research internship at the Scuola Normale Superiore in Pisa, Italy was truly educational in many different aspects. She was able to connect with a diverse population of exceptional students and researchers in a variety of disciplines from all over the world. Academically, the research experience deepened her understanding and increased her technical knowledge. It was stimulating to have the opportunity to work and collaborate on many different topics. Her stay contributed research, knowledge, and international perspective back to the host laboratory, and by sharing her research background, Ko also helped to spread MIRTHE's message and purpose.

A recommendation for future programs would be to encourage greater prior correspondence with the host institution to clearly define the role of the international visitor. In such a way, the initial acclimation time may decrease and a productive collaboration may begin sooner after arrival. Correspondence with future colleagues would also increase initial familiarity and better facilitate the transition of the visitors into a new environment.

Through the funded collaboration, Ko gained an international conscience key to a modern successful career in science. The relationships formed will continue on for years to come and facilitate international camaraderie. Once shared, this international perspective not only benefits those of the scientific community, but those of the general public by spreading international tolerance and respect.

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BRIEF BIOGRAPHIES OF RESEARCHERS

Tiffany Ko is an undergraduate in her junior year currently pursuing a Bachelor's degree in Electrical Engineering and two certificates in Engineering Biology and Materials Science at Princeton University located in Princeton, New Jersey. Previous research focuses include high performance quantum cascade laser design and optimization of QC laser operation for quartz-enhanced photoacoustic spectroscopy (QEPAS). She is currently investigating different fabrication techniques for DFB-QC lasers in the Mid-Infrared Photonics Group located at Princeton University. She is a student member of the IEEE, President of the Princeton University IEEE Student Chapter, and an Education Outreach officer of the Student Leadership Council of MIRTHE.

Richard Green received his PhD from the University of Sheffield, for experimental studies of the structural and optical properties of mid-infrared QCLs, and time-resolved intersubband spectroscopy of self-assembled quantum dots. Since 2004 he has worked at the Scuola Normale Superiore, Pisa, Italy. His current research interests include the

design and fabrication of terahertz QCLs, and studies of their dynamic properties.

David Barate received his PhD in 2005 from the University of Montpellier. Currently he is a Postdoctoral fellow at the National Enterprise for nanoScience and nanotechnology (NEST) research facility located in Scuola Normale Superiore in Pisa, Italy. He has extensive experience and training using molecular beam epitaxy, specializing in antimonide and arsenide materials growth. His current research interests include intersubband physics and devices, quantum cascade lasers, epitaxial growth.

Ji-hua Xu is a scientist at the National Enterprise for nanoScience and nanotechnology (NEST) research facility located in Scuola Normale Superiore in Pisa, Italy.

Aji Annapara is a doctorate student of the Scuola Normale Superiore. His current research interest include intersubband microcavity polariton dynamics.

Alessandro Tredicucci was born in Chiavari, Italy, on January 3, 1968. He received the Ph.D. degree (summa cum laude) in physics from the Scuola Normale Superiore of Pisa in 1997. In 1997 he joined Bell Laboratories, Lucent Technologies, Murray Hill, NJ, in the Semiconductor Physics Research department, where he worked on the development of novel quantum cascade lasers with superlattice active regions. In November 2000 he came back to the Scuola Normale Superiore of Pisa first as assistant professor and, from March 2003, as senior scientist of the INFM (Istituto Nazionale per la Fisica della Materia), now part of CNR. His activity is now mainly concerned with intersubband devices, particularly for the generation and detection of THz radiation and the investigation of new regimes of light-matter interaction. Alessandro Tredicucci has co-authored about 110 journal papers (with over 2100 citations), has given more than 50 invited talks at international conferences, and holds 15 patents. He was the recipient of the 1999 Gilberto Bernardini award and of the 2003 S. Panizza award for opto-electronics of the Italian Physical Society. He was the recipient of the 2005 S. Campisano prize for condensed matter physics of the CNR and of the 2007 Copernico prize for physics.

APPENDIX

Figure 1: LabVIEW program for autonomous LIV characterization.

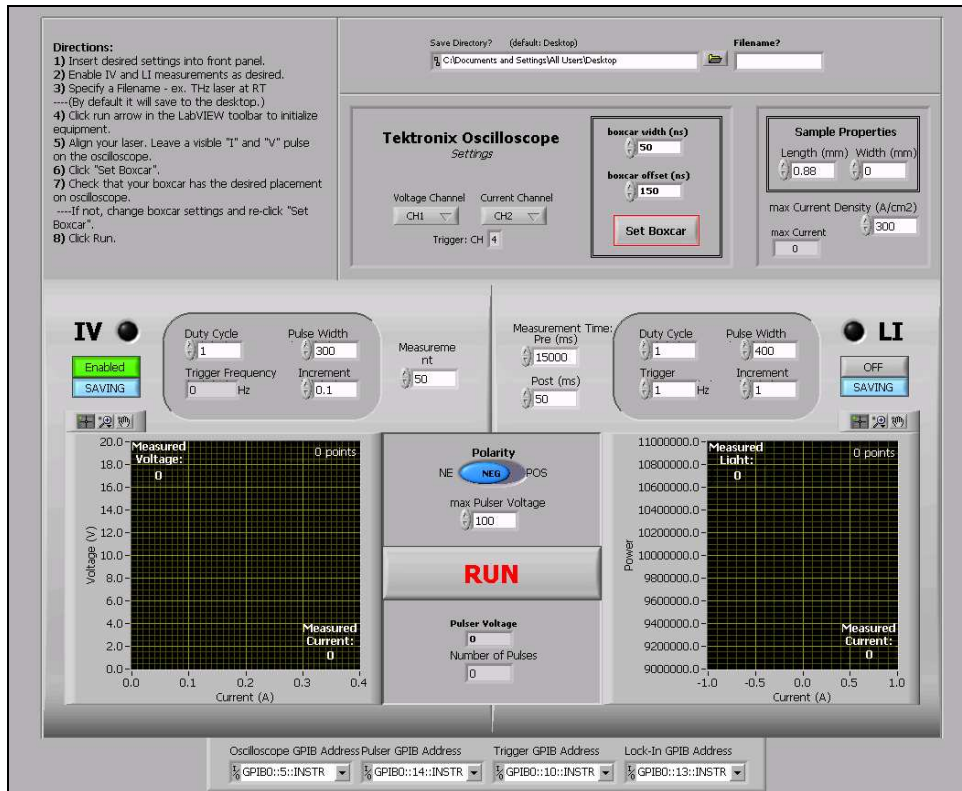


Figure 2: THz QC laser structure and non-linear generation method [1].

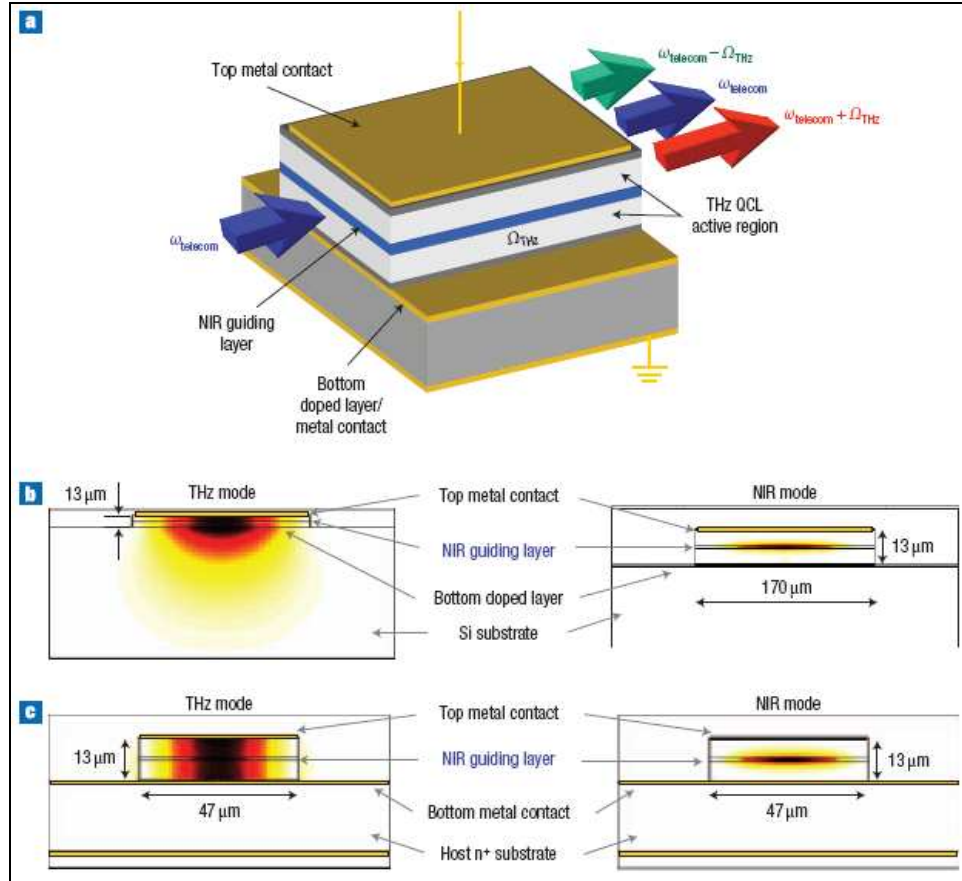


Figure 3: Ultrafast NIR laser setup.



Figure 4: SEM image of dried droplet surface of ordered nanorods.

