UCLA Samueli Electrical & Computer Engineering

Ph.D. Defense

THz Time-Domain Characterization of Amplifying Quantum-Cascade Metasurface

Yue Shen

Advisor: Professor Benjamin Williams

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Abstract Terahertz (THz) quantum cascade lasers (QCLs) are compact electrically pumped unipolar semiconductor laser which can produce a continuous wave radiation of high output power in the range of 1.2 to 5.6 THz. The QC vertical-external-cavity surface-emitting-laser (QC-VECSEL) is an external cavity configuration that has been developed that supports high-power operation with excellent beam quality and broadband tunability. The key component of the QC-VECSEL is an amplifying reflectarray metasurface, based on a subwavelength array of surface radiating metal-metal waveguide antenna elements loaded with QC-laser gain material. Despite its importance, up to now, the spectral properties of the QC-metasurface have been designed by simulations and have only been verified indirectly through observation of the QC-VECSEL lasing characteristics, or by passive FTIR reflectance measurements at room temperature. Furthermore, often the simulations in question use simplified models for the material loss and the QC-gain, where uncertain Drude model parameters for material losses are used, and the detailed interaction of the intersubband transition with the metasurface is neglected. In the past decade, THz time domain spectroscopy (THz-TDS) has been widely used to investigate gain spectra and laser dynamics of THz QC-lasers based on various ridge waveguide geometries.

During my doctoral studies, I designed and built up a reflection-mode THz-TDS system to study amplifying quantum-cascade (QC) metasurface samples as a function of injected current density. The first direct spectral measurements were performed on QC-metasurfaces using reflection-mode THz-TDS. Several different kinds of metasurface were designed that were suitable to be studied by the THz-TDS system. Extremely strong absorption features for QC-metasurfaces whose resonance frequency designed below 3 THz is measured at zero bias, which is associated with coupling between the metasurface resonance and an intersubband transition within the QC material. One nearly perfect absorption case is observed due to the transition from weak to strong coupling condition. Increases in reflectance are observed as the devices are biased, both due to reduction in intersubband loss and the presence of intersubband gain. Significant phase modulation associated with the metasurface resonance is observed via electrical control for some certain metasurfaces, which may be useful for electrical tuning of QC-VECSEL. These results provide insight into the interaction between the intersubband QC-gain material and the metasurface and modify the design rules for QC-VECSELs for both biased and unbiased regions.

Biography Yue Shen is currently a PhD student at the Benjamin Williams' lab in the ECE department at UCLA. He received his B.S. in Electrical Engineering from the Tsinghua University in 2016, and his M.S. in Electrical and Computer Engineering from UCLA in 2019. His research focuses on studying quantum-cascade metasurface using terahertz time domain spectroscopy.

For more information, contact Prof. Benjamin Williams at bswilliams@ucla.edu