UCLA Samueli Electrical & Computer Engineering

Ph.D. Defense

Monolithically Integrated Terahertz Optoelectronics Based on Quantum Well Structures

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Engineering Bldg. IV – Faraday Room #67-124

Abstract Photoconductive terahertz devices have been widely used in terahertz time-domain spectroscopy (THz-TDS) and terahertz frequency-domain spectroscopy (THz-FDS) systems. However, conventional systems require external lasers and free space optical components for pumping, making these systems bulky, complex and not scalable, limiting their practical usage in real world applications. Monolithic integration of photoconductive terahertz devices with on-chip lasers, semiconductor optical amplifiers (SOAs), optical modulators and other passive components would be desired to reduce the size, cost, and complexity of these systems. There has been some effort on monolithic integration of terahertz transmitters with on-chip lasers and modulators. However, the demonstrated signal generation has been limited to frequencies below 110 GHz. Furthermore, realizing these devices require either multiple epitaxy growth steps or heterogeneous bonding of different III/V dies to an SOI photonic substrate, with limited scalability. Moreover, there is no demonstration of using such devices for terahertz detection. Hence, monolithic integration of high-performance terahertz transmitters and receivers with active and passive optical components remain a critical challenge to be addressed. During my doctoral studies, I have conducted extensive research to explore the possibility of using quantum well structures as a platform for monolithic integration of terahertz optoelectronics. In particular, I have designed, fabricated, and characterized the first-generation terahertz transmitters, receivers, lasers, and SOAs based on GaAs/AlGaAs quantum well structure without the need for epitaxy regrowth. By carefully designing the structure of integrated photomixers with SOAs, high optical absorption and low resistive/capacitive parasitics are achieved at the same time. I have also developed an in-depth theoretical model to analyze the performance of these devices used as continuous-wave, frequency-tunable terahertz transmitters and receivers, while considering the ultrafast carrier dynamics inside the quantum wells and at the heterostructure interfaces, as well as device parasitics. The predictions of this theoretical model are in excellent agreement with the experimental results. The first-generation terahertz transmitters offer a broad frequency tunability of 140-500 GHz with power levels of –10 dBm, –20 dBm, –26 dBm and –35 dBm power generated at 140, 310 ,400 GHz and 500 GHz. The first-generation terahertz receivers monolithically integrated on the same chip, offer noise equivalent power levels of 2.3, 3.8, 8.1, 13.7, 15.1 and 93 $pW/Hz^{0.5}$ at 140, 170, 250, 310, 400 and 500 GHz.

Biography Yifan Zhao received his B.S. degree in Physics from Peking University, China in 2017 and M.S. degree in Electrical and Computer Engineering from University of California, Los Angeles in 2019. He joined the Terahertz Electronics Laboratory in Electrical and Computer Engineering department at UCLA to pursue his PhD degree under the supervision of Prof. Mona Jarrahi. His research primarily focuses on monolithic integration of photoconductive terahertz devices with active optical components. He's the recipient of Samueli Fellowship in 2018 and Summer Mentored Research Fellowship in 2021.

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