Microelectronic Terahertz Receiver / Transceiver

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Motivation—The "unconventional" terahertz (THz) electromagnetic spectrum between microwaves and infrared offers unprecedented, disruptive advantages for national security, defense, scientific, and industrial missions. However, THz technology infrastructure still remains immature compared to microwave electronics and infrared photonics. A central component of THz technology, a heterodyne receiver or transceiver, has until now relied on large, expensive, high-maintenance molecular gas tube lasers to supply coherent THz radiation with sufficient power. Clearly any widely practical THz system requires a semiconductor-based microelectronic technology instead. Only recently has this become feasible with the invention of high-power microelectronic THz quantum cascade lasers (QCLs), in which Sandia played a major role. THz QCLs are currently the only solid-state sources of coherent THz radiation with > 1 mW of continuous power. However, it remains to be seen whether the power, mode structure, and noise/stability characteristics of QCLs are sufficiently good that they can serve as useful local oscillators (LOs) and/or coherent illumination sources with microelectronic THz mixers to form an all-solid-state THz receiver or transceiver.

Accomplishments—To test whether a THz QCL can work as an LO source with a solid-state THz mixer we had to develop both a QCL and a semiconductor mixer with compatible frequency ranges and power characteristics. To this end, 2.8 THz QCLs were successfully grown by molecular-beam epitaxy, fabricated, and tested at Sandia to be used as the microelectronic THz LO source. It was estimated that these lasers output between 1 and 2 mW continuous power.

On the mixer end, a Schottky diode mixer that works at the QCL frequency was successfully designed and fabricated through collaboration with NASA's Jet Propulsion Lab at Cal Tech. A photo of the mixer is shown in Fig. 1. This mixer operates from 2.5 to at least 3.1 THz (defined by the LO source frequency) with excellent low-noise characteristics. To achieve optimal noise figure requires 5 to 8 mW of power from an LO source.

Initial tests of how well the QCL operates with the Schottky mixer showed that the mixer can generate a difference frequency signal between two closely spaced coherent modes of the QCL, see Fig. 2. This indicates that the QCL outputs enough power to cause the Schottky to mix with reasonable conversion efficiency. Because the intrinsic linewidth of the Schottky response is very sharp, the Schottky was also used to determine that the linewidth of the QCL is less than 10 kHz, without being stabilized. However, we have not yet been successful in coupling enough power from the QCL to the mixer to operate the mixer at its minimum noise figure.

Significance—These ongoing experiments are the first effort to explore the integration of both semiconductor microelectronic THz sources and mixer to develop a microelectronic THz heterodyne receiver / transceiver. It is highly encouraging that the Schottky mixer can mix two modes of a QCL. Additional power requirements for optimal mixer operation have been identified.

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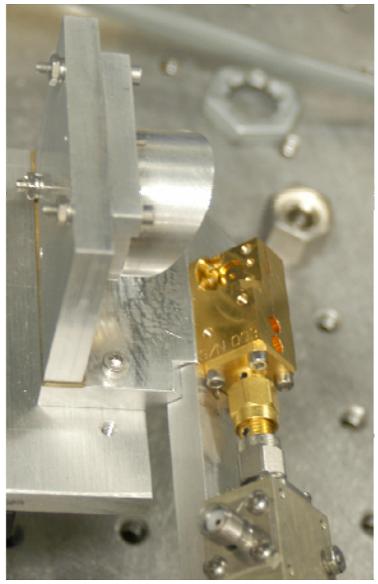

Figure 1. Photo of the Schottky mixer. The actual mixer diode is housed inside the gold-colored block. This mixer block faces an aluminum coupling mirror (approximately 1 inch diameter) that focuses THz light from the QCL LO source into the mixer block. The component below the mixer block supplies electrical bias to the mixer.

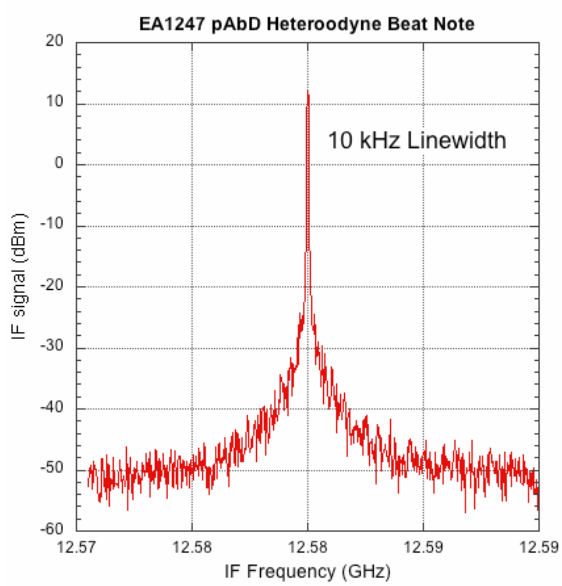

Figure 2. Schottky mixer signal showing the down-converted 12.58 GHz difference frequency between two modes of the 2.8 THz QCL. The width of the mixer signal peak indicates that the QCL output linewidth is no broader than 10 kHz.