

### A HETERODYNE DETECTOR FOR TERAHERTZ SPECTROSCOPY OF PLANETS AND COMETS

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Gaseous species on comets and in planetary atmospheres have unique spectral fingerprints between 100 GHz and 5 THz. The Microwave Instrument for the Rosetta Orbiter (MIRO)<sup>1</sup> with heterodyne receivers based on Schottky diodes at 188 GHz and 562 GHz, has recently demonstrated the power of high-resolution sub-THz spectroscopy in planetary missions as it records spectra of volatile molecules sublimating from a comet. Both the density and strength of microwave transitions increases with increasing frequency, so high-resolution spectroscopy at frequencies between 1 and 5 THz is even more attractive. High resolution spectroscopy in the 1-5 THz region with a nearly quantum limited heterodyne receiver will greatly improve spectral coverage and sensitivity over existing submillimeter heterodyne receivers designed for planetary space applications. The improved sensitivity will reduce the column abundances needed to detect known spectral lines, and open up the possibility of detecting new molecular species never before detected in space.

We are developing a new class of heterodyne detector called a Tunable Antenna-Coupled Intersubband Terahertz (TACIT) detector.<sup>2</sup> TACIT heterodyne detectors promise nearly quantum-limited noise performance at frequencies above 1 THz using only microwatts of local oscillator (LO) power while operating at temperatures compatible with passive cooling. TACIT detectors are sensitive in a  $\sim 100$  GHz wide frequency window that can be tuned broadly in the THz frequency range by simply varying gate voltages.<sup>3</sup> Thus the detection frequencies on an instrument flying a TACIT heterodyne receiver could be reconfigured during a mission, adding the flexibility to search for a range of species with spectral signatures in different frequency bands.

A TACIT mixer is a four-terminal transistor-like device, shown schematically in Fig. 1. The heart of a TACIT mixer is a GaAs “quantum well” containing a two-dimensional electron gas (2DEG) whose resistance is a strong function of the electron temperature. The signal and LO are coupled into the 2DEG by an antenna that is terminated by front- and back-gate contacts located above and below an active region in the 2DEG. When the signal and LO are resonant with an “intersubband transition”—a transition between

quantum-confined states in the quantum well-- the THz radiation is efficiently absorbed, heating the 2DEG and changing its mobility. The intermediate frequency (IF) of a TACIT mixer is read out through a pair of ohmic contacts (source and drain) to the 2DEG. The frequency of the intersubband resonance can be broadly tuned by changing the voltage difference between the front and back gates. Independently, the impedance presented by the active region to the signal and LO can be matched, *in-situ*, to the antenna impedance by varying the carrier concentration in the active region via the field effect, ensuring high quantum efficiency.<sup>2</sup>

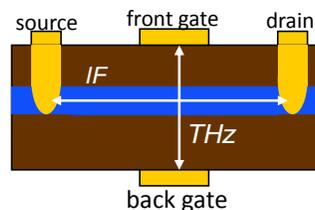


Fig. 1 Schematic of THz detection and intermediate frequency (IF) generation in a TACIT device, where 2DEG channel is shown in blue.

In order to realize TACIT devices, 40 nm GaAs quantum wells with very low impurity concentration containing a 2DEG whose mobility is a strong function of temperature above 10K are grown by molecular beam epitaxy (MBE) at Princeton University. A novel rf embedding circuit is designed at JPL which enables coupling of signal, LO, IF, and DC biases to the four terminals of the device. A fabrication procedure involving multiple photolithography, wet etching and metallization steps is under development at UCSB, aiming to produce low resistance Ohmic contacts as the source and drain leads and metal gates on both surface and backside. In order to have a high responsivity, it is necessary for the resistance of the 2DEG near the TACIT operating temperature to be dominated by thermally-excited phonons rather than impurities or other quenched disorder. This requires the 2DEG have a mobility in excess of  $10^6$  cm<sup>2</sup>/V\*s at 10 K after the complete fabrication process. Moreover, the fabrica-

tion process needs guarantee no short between the gates and source/drain leads.

The research plan is to implement a complete cycle of design, fabrication and testing of a new generation of TACIT detectors. This cycle includes materials science (growth and characterization of a specially-designed, very clean quantum well by molecular beam epitaxy), rf engineering (design of novel antenna and rf embedding circuit), the development and implementation of a new microfabrication procedure, and testing of TACIT detector under DC, microwave and terahertz fields. We are aiming to bring TACIT detectors much closer to realizing their enormous potential for studying gases near comets and planets.

Currently, preliminary test devices have been achieved which undergo dc characterization (dc conductivity and magnetoresistance). These measurement yield the electron gas parameters essential for understanding of the device. More data including current-voltage characteristics, device microwave noise and impedance, as well as the integrated THz circuit (antenna) design are expected soon. These data and their implication regarding the physics of the mixing process in TACIT device will be reported at the meeting.

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