Design, fabrication and testing of semiconductor tunable antenna-coupled intersubband Terahertz (TACIT) detectors

G. B. Serapiglia,[1] Y. Dora,[1,2] M. S. Sherwin,[1,3] M. Hanson[4], A. C. Gossard[2,4] and W. R. McGrath[5]

[1]*Institute for Quantum Engineering, Science and Technology (iQUEST), University of California at Santa Barbara (UCSB)*
[2]*Department of Electrical and Computer Engineering, UCSB*
[3]*Department of Physics, UCSB*
[4]*Department of Materials, UCSB*
[5]*Submillimeter-wave superconductive sensors group, Jet Propulsion Laboratory*

A new type of semiconducting sensor for frequencies in the range 1-5 THz is under development in this UCSB/JPL collaboration. The active region of the device is shown schematically in Fig. 1. THz radiation is coupled into a coplanar antenna (not shown). The antenna is terminated by a resonant absorber which is located between a front and a back gate. The absorber contains an electron gas bound in a quantum well. The Terahertz radiation is absorbed if it is resonant with the frequency of a transition between the quantized states, or subbands, of the quantum well. The absorbed radiation heats up the electrons in the quantum well, changing the resistance between a source and drain. It has been predicted that, when TACIT sensors are operated as heterodyne mixers, receiver noise temperatures of a few hundred K could be achievable at operating temperatures exceeding 20K, with <1 μW of local oscillator (LO) power and IF bandwidths exceeding 10 GHz.[1] TACIT sensors can also be operated as fast, voltage-tunable direct detectors for THz radiation.[2]

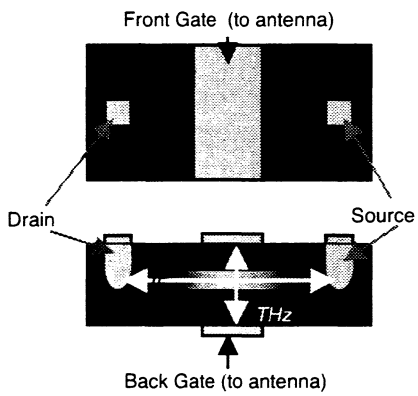

Figure 1: Schematic diagram of active region of a TACIT sensor.

In this contribution, we report on the design, fabrication and testing of TACIT sensors. A novel aspect of TACIT mixers is that they are four-terminal devices—the RF (THz) and IF (GHz) are coupled through separate contacts. This provides design flexibility as well as challenge. To our knowledge, no four-terminal THz mixers have been built. The current design is a modification of a design which is used successfully for superconducting hot-electron bolometers, which are two-terminal mixers. RF is coupled into twin slot dipole antennas which drive coplanar waveguide (CPW). The center conductor of one CPW line is connected to the front gate, the other to the back gate. The IF is coupled out on a microstrip line, which uses the same ground plane as the twin slot antenna. All lines are filtered to avoid RF leaking out along DC or IF lines.

Fabrication of TACIT sensors according to this design requires processing on both sides of the<1 μm thick active region. We have based our process on the Epoxy Bond and Stop-Etch (EBASE) process developed at Sandia National Laboratories.[3] Fig. 2 shows a prototype which has been fabricated and electrically tested. In this device, the twin-slot dipole antennas, ground plane, and filtered DC bias lines to the front and back gates, are visible through a submicron layer of GaAs.

This layer is bonded by epoxy to a carrier wafer of GaAs. The gold surface metallization shows the front gate, which is connected by a via to the center conductor of the underlying CPW line. Also shown are the IF and DC bias lines. All wire bonds are made to the exposed surface.

A processed device has been tested electrically by measuring source-drain current-voltage curves at a range of temperatures from 30 to 150 K. The theory of TACIT mixers[1] predicts that the mixer noise temperature is given by

$$T_N=\alpha^{-1}(8/[\gamma^2 T_e]-2T_e),$$

where T_e is the electron temperature (assumed to be much larger than the lattice temperature), α is the product of RF and IF coupling efficiencies, and $\gamma=1/R(dR/dT_e)$, where R is the source-drain resistance. We will report on values of γ and αT_N extracted from electrical measurements using Eq. 1, and also discuss LO power requirements predicted based on these numbers. We will also discuss progress towards measurements of the NEP of fabricated devices, operating as direct detectors.

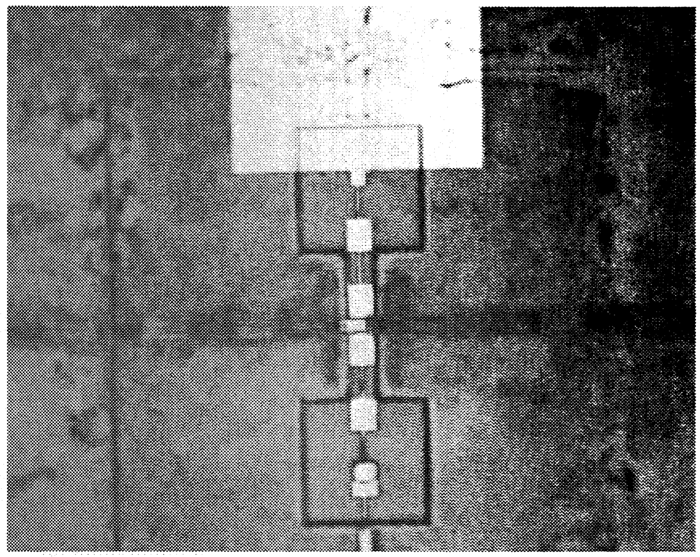

Figure 2: Photograph of prototype TACIT sensor. The thinnest visible gold lines are 1 micron wide.

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