Single Quantum Well Terahertz Plasmon Detectors

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Motivation—The terahertz portion of the electromagnetic spectrum, *i.e.*, frequencies roughly around 10^{12} Hz, lies in a technological gap between conventional electronics, which function at lower frequencies, and conventional photonics, which work at higher frequencies. This gap is a consequence of fundamental considerations regarding electron transit times and band gaps in metals and semiconductors. Despite this, there is a great deal of interest in THz generation and detection as it possibly enables, among other things, a variety of defense- and security-related applications ranging from covert inspection for concealed weapons to the stand-off detection of chemical hazards and energetic materials. To get around basic electronic limitations on the frequency range of THz detectors, we have been exploring the use of low-dimensional plasmon charge excitations driven by THz radiation.

Accomplishment—The basic detector is a depletion mode field-effect transistor (FET) structure fabricated from high mobility modulation-doped single- or double-quantum well GaAs-AlGaAs heterostructures (Fig. 1). As shown, the device consists of source and drain electrical contacts along with a grating gate to couple in THz radiation. Plasmons are collective charge density oscillations that resonate at frequencies orders of magnitude higher than can be reached by conventional electronics. The resonant frequency of a plasmon is set by the carrier density in the quantum well. The function of the gate in the structure shown is therefore to tune the electron density in the device and thus adjust the resonant plasmon frequency to match the THz radiation illuminating the device. Initial investigations of grating-gate detectors were performed using double-quantum wells. In that work, the basic principles of detection using plasmons were uncovered. It was found that the grating-gate detector exhibited a photoresponse when the plasmon frequency under the grating gate was tuned to the frequency of the incident illumination. This electrically tunable 'spectrometer on a chip' capability is not found in other THz detectors (or in more conventional detectors used in the visible regime, for that matter).

Recent work on grating-gate detectors has shown that the same electrically tunable photoresponse arises in detectors made from single-well material (Fig. 2). Several new detector geometries were investigated, including sub-wavelength detectors and a 'split grating-gate' detector. The 'split grating-gate' detector utilizes an intentionally built-in nonlinearity that increases detector responsivity by several orders of magnitude while still retaining tunability.

Significance—In double layer devices, one needs to be concerned with mechanisms, such as interlayer tunneling, that are not easily understood when combined with plasmon excitations. The realization of single-well grating-gate detectors immediately simplifies both device fabrication and modeling by removing the second well.

From a practical standpoint, single well devices are more like conventional FETs that are widely used in electronics. Thus, integration of other useful components, such as on-chip signal amplifiers, becomes possible.

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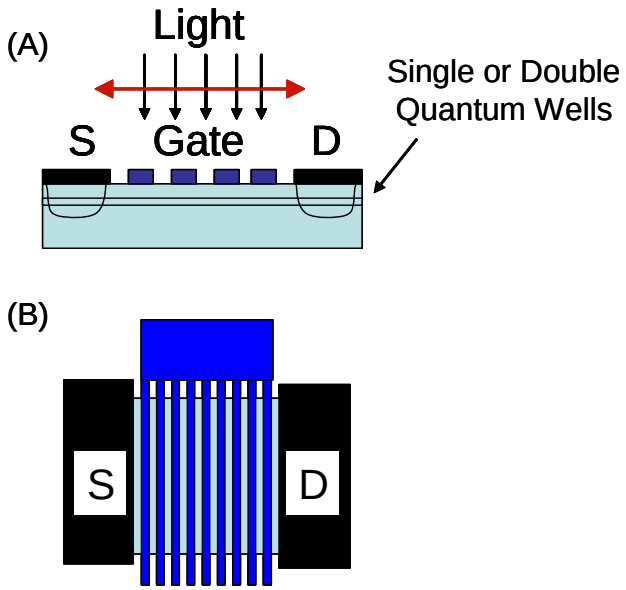

Figure 1. Basic geometry of the grating-gated plasmon THz detector. Device cross-section and illumination conditions are shown in (A). The detector operates at normal incidence with the electric field polarized across the grating. Part (B) shows the top down view of the detector. Gratings used range from 2mm x 2mm down to 0.2 mm x 0.2 mm in area and have a 4 µm period with a 50% duty cycle *(i.e.* 2 µm gold + 2 µm gap).

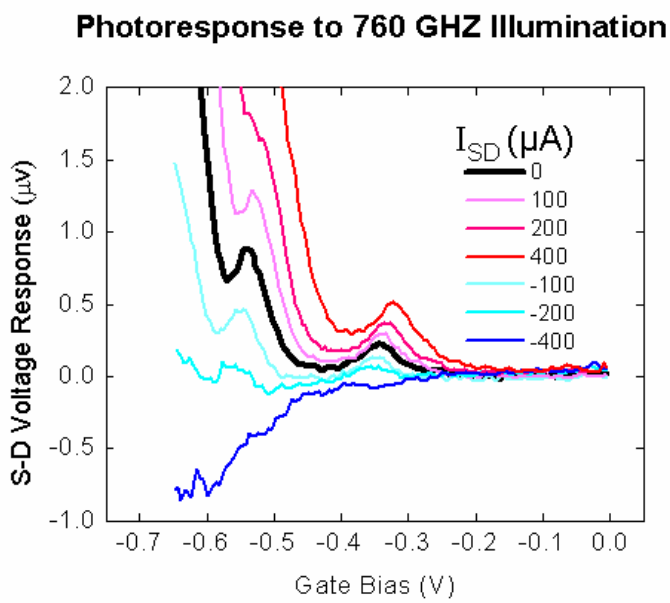

Figure 2. Typical photoresponse of a single-well plasmon detector to 0.76 THz. The black trace shows a photovoltaic response (zero source-drain current). Resonant peaks are observed at -0.35V and -0.55V gate bias. Positive currents add a positive photoconductive response component, and negative currents add a negative photoresponse that competes with the photovoltaic signal.