# *Single Quantum Well THz Split Grating-Gate Detectors*

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**Motivation**—The terahertz (THz -300µm wavelength or $10^{12}$Hz) portion of the frequency spectrum lies in a gap between where conventional electronics can be driven and where optical transitions in materials and devices can be easily manipulated. There is a great deal of interest in the THz generation and detection as it enables a variety of national security applications from seeing through clothing to explosives detection. On the detection side of this problem, plasmon based grating-gate detectors have been explored as a tunable detector of THz radiation.

**Accomplishment**—The split grating-gate detector is a depletion mode field-effect transistor (FET) structure fabricated from high mobility modulation doped single or double quantum well material (inset Fig. 1). As shown, the device consists of source and drain electrical contacts along with a set of 3 gates; a source gate, drain gate, and a finger gate which is just a single strip dissecting the device. Plasmons are collective excitations of electrons that can 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 underneath the source and drain gates. The finger gate is independently biased beyond the pinchoff voltage in the material and it tunes the responsivity of the detector. IV traces are shown in Fig. 1 at several different finger gate biases. Beyond the pinchoff voltage (approximately -0.7V), the device takes on diode-like characteristics.

Previous work demonstrated that plasmon detectors using only a single gate worked as tunable THz detectors. However, the noise equivalent power (NEP), which defines how good a detector really is, was only $10^{-5}$ W/√Hz; our goal is to reach an NEP of $10^{-9}$-$10^{-10}$ W/√Hz.

The photoresponse of the single well split gate detector to 432µm radiation, at several different device operating points, is shown in Fig. 2a. The resulting responsivity of several V/W and an NEP of $10^{-7}$ W/√Hz is a 3 order of magnitude improvement in the photoresponse magnitude and 2 orders of magnitude improvement in NEP when compared to the standard single gate plasmon detector (inset Fig. 2a). By measuring detectors of various sizes, we have also found that only a very small portion of the detector, as low as 5% around the single finger gate, is optically active. This bodes well for other device designs that can take advantage of the split gate mechanisms while maintaining a larger active area. For example, a suspended version of this detector has been made from double well material (which does not perform as well as single well material) and demonstrated a NEP of $10^{-8}$ W/√Hz. In the past year, we also demonstrated video-rate spectral sweeps using the single well split-gate detector as shown in Fig. 3.

**Significance**—Plasmon detectors have been demonstrated as on-chip THz spectrometers with no moving parts. The primary obstacle to their practical use is the NEP. This recent work made several large steps towards our targeted NEP of $10^{-9}$-$10^{-10}$ W/√Hz. We currently see no obstacles to further developing these detectors to reach this goal.

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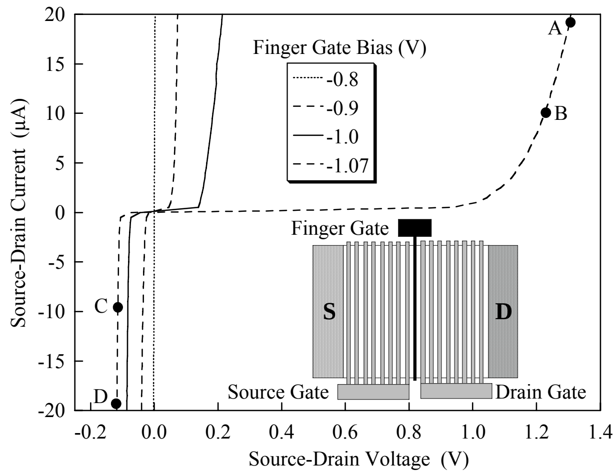


**Figure 1**. Source-drain current-voltage characteristics (in the dark) of the QW FET in split-gate operation at various values of the finger gate bias with respect to the drain. A, B, C, and D indicate operating points for the FIR response measurements shown in Fig. 2(a). Inset: schematic plan view of the QW FET split-gate configuration (not to scale).

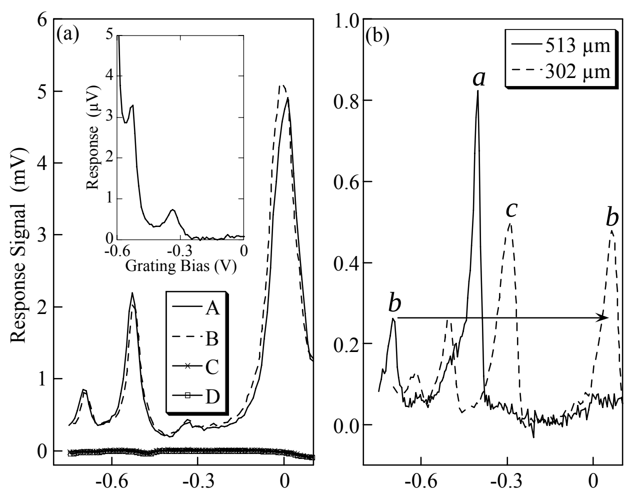


**Figure 2**. (a) FIR response to 432 μm as a function of grating gate bias in the two operating modes. Inset shows response in single-gate mode. Main figure shows operation in split-gate mode with finger bias = –1.07 V. The curves A. B. C. and D correspond to the source-drain dc operating biases shown in Fig. 1. (b) FIR response of the same device in split-gate mode to 513 and 302 μm. Peak labels *a, b, c* indicate the harmonic mode to which each peak corresponds as mapped out in Fig. 3 inset. The arrow indicates how the *b* mode peak moves as wavelength is decreased.

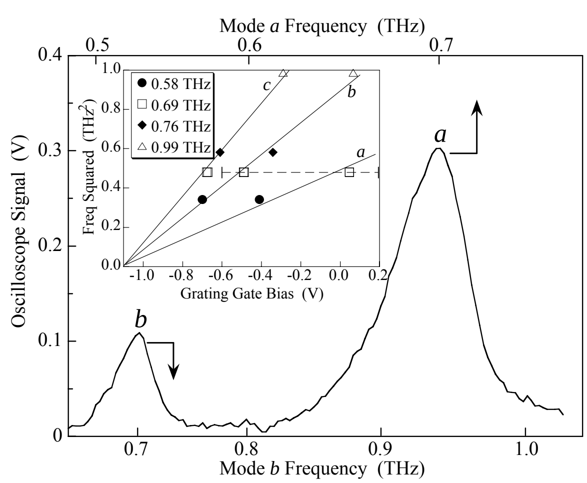


**Figure 3**. Inset: Plasmon mode map showing how resonances fit to the dispersion relation of (1). The line fits *a, b,* and *c* group the data into three modes. The dashed line indicates the range of the gate bias sweep used to generate the main figure, which covers two 432 μm modes. Frequency scales in the main figure are obtained from gate bias via the slopes of the *a* and *b* lines. Main: Spectrum of two plasmon modes excited by 432 μm light. The grating gate was swept from –0.6 to +0.2 V in 12.5 ms. The peak labeled *a* corresponds to the *a* line of the inset and uses the upper frequency scale, while the peak labeled *b* corresponds to the *b* line of the inset and uses the lower frequency scale.