Millimeter Wave Mixing Using Plasmon and Bolometric Response in a Double-quantum-well Field-effect Transistor

by ***Mark Lee, Michael C. Wanke, and John L. Reno***

Motivation—Coherent charge density oscillations (plasmons) in a high-mobility two-dimensional electron gas (2DEG) can be exploited to circumvent physical limits on maximum operating frequency in conventional electron-drift transistors. This speed increase arises from the fact that 2DEG plasmons have velocities ten times faster than electron drift. Typical 2DEG densities from 10^{10} to 10^{12} cm^{-2} yield plasmon frequencies in the 100 GHz to 1 THz range, making plasmon devices attractive for THz applications. The ability to electrically tune the density and hence the plasmon resonance via a gate voltage in a field effect transistor (FET) offers highly desirable new functionalities, such as "spectrometer-on-a-chip" capability.

Accomplishment—We have conducted the first experimental measurements on heterodyne mixing in a plasmon-based device. The mixer is a grating-gated GaAs-AlGaAs double quantum well (DQW) FET designed to have plasmon resonances from 100 to 200 GHz. Mixing is found to have two distinct regimes dependent on gate bias. Close to pinch-off the device exhibits a broadband response which is well-described as a bolometer. The conducting regime shows a gate-tunable plasmon resonance that has more complicated nonlinear behavior than a bolometer. The difference frequency (IF) or signal bandwidth can be fairly wide, > 2 GHz.

Figure 1 shows the detection responsivity vs. gate bias V_g at 94, 135, and 145 GHz. Two response regimes are evident. Above pinch-off, a resonant response to 145 GHz is at $V_g = -2.11$ V, the signature of a plasmon excitation. At more negative gate bias a partial resonance peak in response to 135 GHz is at $V_g \approx -2.25$ V. No resonance at 94 GHz is seen. At $V_g < -2.4$ V, all responsivity curves show a large rise that goes up to almost 50 V/W independent of frequency. The plasmon and pinch-off regimes have distinct mixing characteristics. Figure 2 shows spectra of the IF power for an 87 MHz difference frequency between two sources near 145 GHz. Figure 2(a) is with $V_g = -2.11$ V, the 145 GHz plasmon. A complicated series of harmonics of the IF is seen. Figure 2(b) is with the same parameters except $V_g = -2.42$ V, near pinch-off. Figure 2(b) consists almost solely of the fundamental IF with only a very small 2 IF distortion. It is clear that the IF generation mechanisms for the plasmon and pinch-off responses are fundamentally different.

Likewise, the IF bandwidth for plasmon mixing is distinctly different from the pinch-off response. Figure 3 shows the conversion gain η as a function of the IF. Figure 3(a) is taken at $V_g = -2.11$ V, on the 145 GHz plasmon. Here the IF bandwidth exceeds the 2 GHz instrumental limit. Figure 3(b) is again the same parameters except with $V_g = -2.42$ V, near pinch-off. Here the IF bandwidth can be fit to a Lorentzian with bandwidth of 620 MHz.

Significance—Development of electronics for very high frequency applications significantly above 100 GHz presents a basic challenge to solid-state physics because electron transit and scattering times are too slow to follow such rapidly oscillating fields. We have shown definitively that plasmon excitations in a high-mobility 2DEG heterostructure have great potential as the basis for fast, wide signal bandwidth, frequency-agile electronics in the 100 GHz to 1 THz frequency range.

Sponsors for various phases of this work include: Laboratory Directed Research & Development, Defense Advanced Research Projects Agency, and Other Federal Agency Work for Others

Contact: Mark Lee; Semiconductor Material & Device Sciences, Dept. 1123
Phone: (505) 844-5462, Fax: (505) 844-4045, E-mail: mlee1@sandia.gov

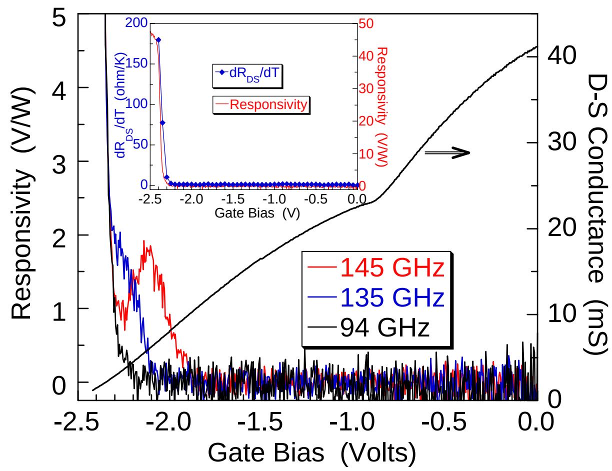

Figure 1. Drain-source conductance and responsivity in response to 94, 135, and 145 GHz as a function of V_g. Inset: 94 GHz responsivity and temperature slope of the drain-source resistance.

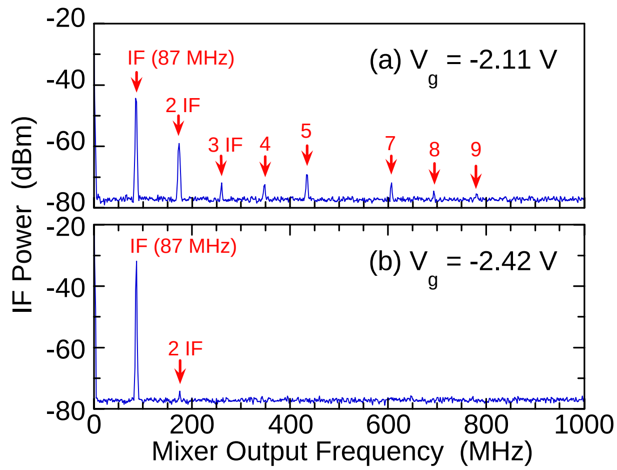

Figure 2. Spectrum of the IF an 87 MHz difference frequency between two sources near 145 GHz. In (a) V_g is held at the 145 GHz plasmon, while in (b) V_g is held in the pinch-off response.

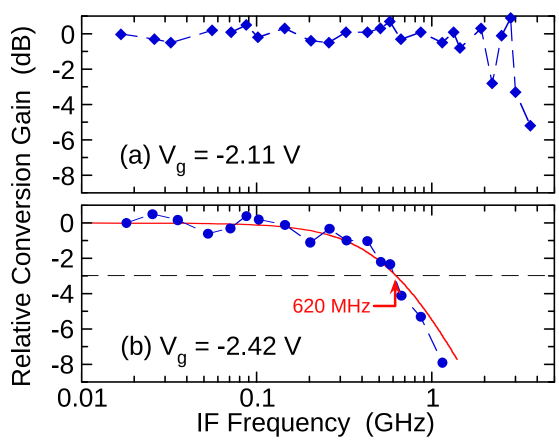

Figure 3. Mixer conversion gain bandwidth. In (a) V_g is held at the 145 GHz plasmon while in (b) V_g is held in the broadband pinch-off response. The red curve in (b) is a fit using a Lorentzian.