Tunable Heterodyne Mixer using Plasmon Modes in a Grating Gated Double-Quantum-Well Field Effect Transistor

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Double quantum well (DQW) semiconductor heterostructures fabricated from high-mobility two-dimensional electron gases (2DEGs) can serve as tunable, sensitive, and possibly fast millimeter- and submillimeter-wave detectors by exploiting long wavelength photons to promote coupling of interwell charge excitations. Recently, DQW field-effect transistors (FETs) in which the gates are periodic metal gratings have been shown to function as tunable incoherent direct detectors between 500 to 700 GHz.[1] These DQW-FETs showed resonant photoconductance with $Q \sim 20$ at frequencies selected by the fixed (for a given device) grating period and the continuously variable gate voltage. A device with a 4 μm gate grating period could be tuned from 570 to 660 GHz by varying the DC gate bias between -1.5 to -0.5 V. This photoresponse was determined to arise from the excitation of plasmon modes in the DQW system. The gate bias depletes the electron density thereby changing the plasmon resonance frequency, initially in the upper quantum well at small negative biases and subsequently in both quantum wells. The gate grating period selects discrete plasmon wave vectors, leading to harmonic resonances in the photoresponse. Interestingly, the strength of the resonant photoresponse was observed to be maximal at temperatures between 25 to 40 K, decreasing at both lower and higher temperature. The composite plasma oscillation of the coupled quantum wells under illumination is complicated and as yet remains incompletely understood. The presence of both quantum wells appears to be necessary to produce the tunable resonant photoresponse.

The use of a DQW-FET in coherent detection as a tunable heterodyne mixer has not previously been addressed. Several properties of the DQW-FET indicate that it may function well in mixer applications requiring electrical tunability, low LO power, and modestly wide IF bandwidths for a resonant detector. The resonant response of these devices suggests that proper coupling of the electromagnetic field to the DQW system can lead to relatively small required LO powers. Current rise-and-fall time measurements have shown that the DQW-FET's direct response time is less than 0.7 μs, which was the limit of the light source and measurement equipment time constants. These devices also have relatively low sheet resistances and can be designed to operate near 50 Ω for impedance matching purposes.

We will present measurements of a grating-gated DQW-FET operating as a heterodyne mixer. The devices are fabricated from a modulation doped GaAs/AlGaAs DQW heterostructure with 20 nm wide wells separated by a 7 nm barrier. The nominal charge densities in the wells are 1.7×10^{11} cm^{-2} in the upper (closer to the gate) and 2.6×10^{11} cm^{-2} in the lower well. The grating gates are 70 nm thick TiAu patterned into gratings with periods between 4 to 16 μm. The devices will be tuned to resonate near the 94 GHz center frequency of a tunable Gunn oscillator. The basic properties of the mixer will be discussed and analyzed, including the conversion gain, required LO power, IF bandwidth, and temperature dependence.

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[1] X. G. Peralta, S. J. Allen, M. C. Wanke, N. E. Harff, J. A. Simmons, M. P. Lilly, J. L. Reno, P. J. Burke, J. P. Eisenstein, Appl. Phys. Lett. **81**, 1627-1629 (2002)