Electron-Drift and Plasmon Response in Millimeter- to -Submillimeter-wave Mixers Based on High Electron Mobility GaAs-AlGaAs Heterostructures

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Millimeter-to-submillimeter-wave radiation can couple to a very high mobility (10^6 to 10^7 cm^2/V·s at 4 K) electron gas in a III-V semiconductor heterostructure interface or quantum well in two distinct manners that are both useful in detection and mixing applications. The first and more conventional response is based simply on electron drift, while the second response is for the radiation to resonantly excite coherent charge density oscillations, or plasmon modes, of the electron gas. We will show examples and contrast the fundamental limitations on frequency response and mixing characteristics resulting from the different physics of the two responses.

We have shown[1] that hot-electron bolometer (HEB) mixers made from a high-mobility two-dimensional electron gas (2DEG) can enter a regime where neither energy nor momentum relaxes in a channel between source and drain electrodes, leading to ballistic electron drift. For a source-drain channel of length L, this minimizes the charge transit time τ_{tr} and hence maximizes the intermediate frequency (IF) bandwidth to $f_{3dB} = v_F/2\pi L$, where v_F, the Fermi velocity, is typically ~ 10^7 cm/s in a 2DEG. Even for $L > 1$ μm, IF bandwidths approaching 40 GHz have been observed. The IF spectrum of such an HEB mixer has very low harmonic distortion, as expected for the square-law non-linearity of a bolometer, while the responsivity and conversion gain are generally low, owing to the small temperature coefficient of resistance of the high-mobility 2DEG. In addition, in the ballistic electron drift regime the 2DEG has kinetic inductance that will degrade coupling to the electromagnetic field as local oscillator (LO) frequency increases. We estimate that, for practical antenna/mixer geometries and electron densities, the inductive reactance will set an upper limit on LO frequency coupling of roughly 500 GHz.

By contrast, the plasmon response we have observed is resonant and not limited by kinetic inductance. Using a grating-gated field-effect transistor geometry, resonant plasmon response has been observed from 135 to nearly 700 GHz in various devices.[2] In a single device, the resonant frequency of the response can be tuned continuously over a ~ 200 GHz range by an applied gate voltage bias. Heterodyne experiments show that, unlike an electron-drift device, the IF bandwidth of this detector operated as a mixer is not limited by the plasmon transit time, but more likely by the plasmon lifetime. The measured IF bandwidth of approximately 8 GHz is in rough agreement with the half-width of the observed plasmon resonance peak. The IF spectrum of the plasmon mixer also shows significant harmonic content, indicating that the non-linear mechanism generating the IF is significantly more complicated than a simple square-law.[3] We are also investigating plasmon detector configurations that could significantly improve responsivity and conversion gain.

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[1]Mark Lee, L. N. Pfeiffer, and K. W. West, Appl. Phys. Lett. **81**, 1243 (2002)
[2]X. G. Peralta, *et al*., Appl. Phys. Lett. **81**, 1627 (2002)
[3]Mark Lee, M. C. Wanke, and J. L. Reno, Appl. Phys. Lett **86**, 033501 (2005)