Very Wide IF Bandwidths in High Mobility Two-Dimensional Electron Gas Semiconductor Heterostructure Mixers

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There has been great progress in the development of superconducting hot-electron bolometers (HEBs) for use as millimeter and sub-millimeter wave mixers. In particular, the diffusion-cooled niobium HEB has demonstrated low noise, low local oscillator (LO) power requirement, and an intermediate frequency (IF) bandwidth of 2 to 10 GHz in devices with deep sub-micron channel lengths.[1] Yngvesson has suggested[2] that the same principle could be applied to the two-dimensional electron gas (2DEG) in a GaAs-AlGaAs heterostructure. Because of the extremely high electron mobilities obtainable in a 2DEG, IF bandwidths much wider than possible in a superconductor should be achievable in much larger devices, with acceptable compromises in terms of gain, noise, and LO power.

We fabricated antenna-coupled HEB mixers using very high mobility 2DEGs in a GaAs–$Al_{0.28}Ga_{0.72}As$ heterostructure. The 2DEG mobility is 3.1 x 10^5 cm^2/V-s at 77 K and 7.5 x 10^6 cm^2/V-s at 1.5 K, with a sheet carrier density of 2.4 x 10^{11} cm^{-2}. HEB mixers with channel lengths L ranging from 2 to 10 μm were fabricated by etching mesas into the heterostructure, and the ohmic contacts to the 2DEG were coupled to log-periodic antennas and co-planar waveguides. Heterodyne mixing was done using a fixed 115 GHz source and a tunable 115 to 140 GHz source, both coupled in quasi-optically. The IF bandwidth of the measurement system was 20 GHz, limited by an IF low-noise amplifier.

Operating at 77 K, we directly measured 3 dB IF bandwidths ranging from 3 up to 19 GHz corresponding to mixers with L of 10 μm down to 4 μm, respectively. In mixers with shorter L, bandwidths as high as ~ 70 GHz in a 2 μm long device can be extrapolated from Lorentzian fits to the conversion gain roll-off. These bandwidths are all limited by the transit time of a hot electron to move across the channel. For mixers with $L > 4$ μm, the 3 dB frequency scales as L^{-2}, indicating that the hot electrons diffuse across the channel. The diffusion constant obtained from the data is 1.9 x 10^3 cm^2/s. When $L < 4$ μm, the transit time becomes limited by ballistic motion across the channel.

The conversion gain measured is about –16 dB at 0.5 GHz IF using approximately 10 μW of LO power. The conversion gain is only weakly dependent on L, but appears to have some correlation with the DC contact resistance. Preliminary noise power measurements show a system noise temperature of 3500 K operating at 77 K. These results and their relation to calculated expectations[2] will be discussed.

[1] B. S. Karasik, M. C. Gaidis, W. R. McGrath, B. Bumble, and H. G. LeDuc, Appl. Phys. Lett. **71**, 1567 (1997)

[2] K. S. Yngvesson, Appl. Phys. Lett. **76**, 777 (2000)