THz Heterodyne Sensors Using Superconducting MgB_2

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Abstract—Since its discovery in 2001, the expectations have been high for magnesium diboride (MgB_2) to find multiple applications in superconducting electronics, including radiation detectors. Operation at 20+ K rather than at liquid helium temperatures is the key here, especially for sensors intended for space use. However, until recently not much has been done mostly due to the challenge of obtaining thin films with high critical temperature (T_C) close to the bulk value of 39 K. The Hybrid Physical-Chemical Vapor Deposition (HPCVD) technique has been a breakthrough in the thin-film technology yielding superior c-axis oriented MgB_2 films as thin as 5 nm and with a critical temperature of 36-38 K. A combination of a high T_C, an unusually high sound velocity in MgB_2 (≈ 8 km/s), and a good acoustic impedance match to Al_2O_3, MgO, and SiC substrates greatly accelerates the thermal relaxation of non-equilibrium electrons thus enabling promising applications in THz Hot-Electron Bolometer (HEB) mixers. Indeed, an 7-8 GHz intermediate frequency (IF) in HEB mixers has been already demonstrated. Our more recent achievement is a demonstration of an operation of the spiral antenna coupled MgB_2 HEB working between 4 K and 15 K without any sensitivity degradation. The respectable receiver's (no correction) DSB noise temperature T_M = 2,000 K @ 600 GHz and T_M = 3,600 K @ 1.89 THz has been measured. The ultimate goal here is to achieve a broadband mixer for [OI] @ 4.7 THz line detection where an IF bandwidth ≈ 8 GHz is required for capturing complete line spectra across the galaxy. An ongoing material development work addresses manipulation of the lattice disorder in the film in order to reduce the granular structure in the film thus increasing the uniformity of the resistive state and overall HEB mixer performance.

Besides the HEB, we have achieved high-quality planar Josephson junctions (JJ) with an I_CR_N product approaching 5.3 mV have been already studied as radiation mixers. Even without optimization, they demonstrated a noise temperature ≈ 600 K @ 600 GHz. The mixing was observed all the way up to 2 THz where T_M ≈ 2,000 K. The noise temperature degrades slightly (a 20% increase) between 10 K and 20 K. The other advantages of the JJ mixer are the unlimited IF bandwidth and smaller than in HEB required LO power. It still remains to be seen whether the quasiparticle tunneling branch can be utilized for mixing but the possibility to use MgB_2 for the device ground plane, antenna, and wiring is quite real. This may help to improve the state-of-the-art of Superconductor-Insulator-Superconductor (SIS) mixers. Another application area for the MgB_2 JJ's may be in the on-chip integrated THz sources (e.g., frequency multipliers, flux-flow oscsillators).

In this talk, we will overview the results obtained so far and for the above detectors and discuss the ways to improve their performance.