Characterization of MgB_2 Superconducting Hot Electron Bolometers

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***Abstract*— Hot-Electron Bolometer (HEB) mixers have proven to be the best tool for high-resolution spectroscopy at the Terahertz frequencies. However, the current state of the art NbN mixers suffer from a small intermediate frequency (IF) bandwidth as well as a low operating temperature. MgB_2 is a promising material for HEB mixer technology in view of its high critical temperature and fast thermal relaxation allowing for a large IF bandwidth. In this work, we have fabricated and characterized thin-film (~ 15 nm) MgB_2-based spiral antenna-coupled HEB mixers on SiC substrate. We achieved the IF bandwidth greater than 8 GHz at 25 K and the device noise temperature < 4000 K at 9 K using a 600 GHz source. Using temperature dependencies of the radiation power dissipated in the device we have identified the optical loss in the integrated microantenna responsible as a cause of the limited sensitivity of the current mixer devices. From the analysis of the current-voltage (IV) characteristics, we have derived the effective thermal conductance of the mixer device and estimated the required local oscillator power in an optimized device to be ~ 1 μW.**

***Index Terms*—Hot Electron Bolometers, MgB_2, Superconducting Devices, Terahertz Mixers**

I. Introduction

Superconducting Hot Electron Bolometers (HEBs) are the best choice for high-resolution spectroscopy in the far-infrared regime [1]. While there exist direct detectors with sensitivity far beyond the quantum noise limited mixers, heterodyne instruments allow for superior spectral resolution of $\lambda/\Delta\lambda \approx 10^6$-$10^7$ which is important for understanding chemical processes in star forming molecular clouds. SIS mixers have been shown to have sensitivity just a few times higher than the quantum limit, and have no bandwidth limitations due to small inherent time constants. They are, however, limited to frequencies below that set by the superconducting gap Δ, of the materials used. The cut-off frequency in practical SIS mixers does not exceed 1.3 THz [2], and beyond this, only HEBs have shown any promise. Hershel HIFI was a good example of HEBs exceeding the limitations of other detectors by scanning the galactic center (GC) for the CII line at 1.9 THz [3]. The state of the art HEB technology uses NbN films as thin as 3.5 nm [4]. While this technology is fairly mature, there are still some serious limitations which, if exceeded, could significantly benefit future FIR missions. The critical temperature, T_c, of NbN thin films ranges from about 9-11 K which limits operation to around 4.2 K. A combination of the electron-phonon time, τ_{e-ph}, and the phonon escape time, τ_{es}, sets the fundamental limit for the intermediate frequency (IF) bandwidth. In the case of NbN, the IF bandwidth is generally of the order of 3 GHz [5] and while such a bandwidth is sufficient for spectroscopic studies of the GC at frequencies of 1.9 THz, Doppler broadening at this distance would mean that 7-8 GHz of bandwidth would be required for the same velocity span at the 4.7 THz OI line.

MgB_2 has a higher critical temperature than NbN which implies a stronger electron-phonon interaction and a much shorter time constant or larger IF bandwidth. The basic metallic structure has two superconducting gaps [6] which should not have a significant impact on the performance of an HEB made with MgB_2 films given the fact that HEB mixers operate in the resistive state when the gap is heavily suppressed. Indeed, some initial work has been done describing the potentially high performance of MgB_2 mixers [7-9]. The main issue in the past was the difficulty in developing ultrathin films with high critical temperature for HEB fabrication, necessary because the effective time constant which establishes the IF bandwidth is highly dependent on the film thickness d ($\tau_{es} \sim d$).

The hybrid physical-chemical vapor deposition (HPCVD) method of growing MgB_2 films has produced the highest quality films in the world [10]. The high pressure-high temperature process grows epitaxial films on SiC substrates with superconducting properties better than in the bulk material. It has been shown that these films can maintain good superconducting properties even at film thicknesses around 10 nm [11]. The island growth of HPCVD grown MgB_2 films, however, limits their thickness to around 7-8 nm [12].

In this work, we have developed a fabrication process for spiral antenna-coupled devices and done characterization of these devices for varying bath temperatures and pumping frequencies. We have shown that MgB_2 mixers have a behavior qualitatively similar to that in the state of the art NbN devices using DC measurements as well as with LO pumping

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