THz Low Noise Mixers for Sub-mm Astronomy

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I. INTRODUCTION

Terahertz (THz) or submillimeter (Sub-mm) waves have much lower loss in molecular and dust clouds in space comparing to infrared (IR) waves. Hence, THz range is preferable for gas "fingerprinting" to investigate distant objects such as star-forming regions, molecular clouds, stars, or interstellar medium [1]. Low intensity of detected signals forces to use cryogenic low noise detectors. A high spectral resolution ($>10^6$) and broad instantaneous bandwidth are also required to analyse the dynamical behaviour of astronomical objects manifested in Doppler shifted line emission. At frequencies >1 THz hot-electron bolometer (HEB) mixers are the only choice for these applications [2]. They were used in many receivers for astronomical observation programs, e.g. the HIFI instrument of the Hershel Space Observatory [3]. The HIFI instrument allowed for observation of very weak frequency-shifted emissions from two arms of the Galaxy M82 moving toward and from us (see Fig.1).

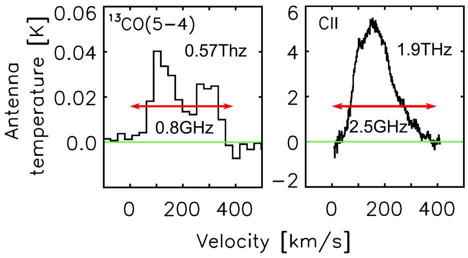

Fig. 1. Observed spectra of Galaxy M82 by the Hershel Space Observatory: CO line at 0.57 THz by SIS mixers and CII line at 1.9 THz by HEB mixers [3].

The large difference in velocity of the Galaxy M82 arms of 400 km/s resulted in a rather broad linewidth of about 2.5 GHz for the 1.9 THz CII spectral line. The line barely fitted into the nominal bandwidth of the used mixer of 2.4 GHz. However, it was not enough for reliable observation, because the baseline of the signal could not be defined properly. The gain bandwidth (GBW) of the current state-of-the-art NbN HEB mixers is <4 GHz, which is significant limitation for some astronomical applications. Furthermore, a low superconducting critical temperature (T_c) of NbN HEB mixers forces to use liquid helium (LHe) for device cooling, which reduces the operation time of spaceborne missions. The MgB_2 HEB mixer can solve both of these problems. A high T_c of MgB_2 (39 K in bulk) allows for operation at bath temperatures >20 K and a GBW >10 GHz. But it remained unclear yet what noise temperature can be achieved if a T_c approaches these high values. A relatively high receiver noise temperature of 4000 K was reported for the 15 nm thick MgB_2 HEB mixer with a T_c of 33 K [4].

II. RESULTS

The highest T_c of our MgB_2 films deposited on Al_2O_3 substrate using molecular beam epitaxy is about 22–24 K for 20 nm thickness. The MgB_2 HEB mixer has been fabricated of one of such films. The submicron size of $1\times0.2\,\mu m^2$ and subsequent low local oscillator (LO) power requirement made it possible to perform noise measurements with a 1.6 THz far-infrared laser LO. The double sideband (DSB) receiver noise temperature vs intermediate frequency (IF) was measured in a quasi-optical setup using LHe cryostat at 4.2 K and 12 K bath temperatures with a Y-factor technique (see Fig. 2). The

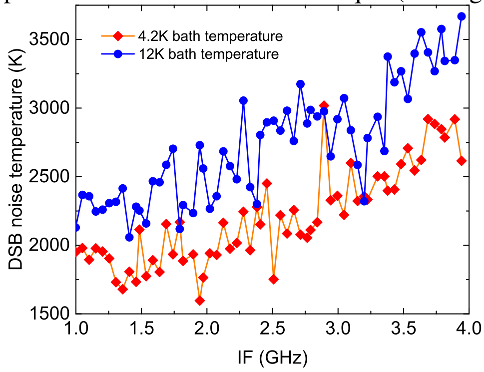

Fig. 2. The DSB receiver noise temperatures (corrected for optical losses) at 4.2 K (diamonds) and 12 K (circles) bath temperatures at a 1.6 THz LO.

increase in noise temperature was from 1700 K to 2150 K, while a noise bandwidth left 5 GHz. In addition, the mixer conversion gain was measured using U-factor [5]. It also left the same at both bath temperatures and was -15 dB with a 3.5 GHz GBW.

III. CONCLUSIONS

It was demonstrated that the MgB_2 HEB mixer with a T_c of 22 K can operate above 12 K with just a 25% increase of the receiver noise temperature compared to that at 4.2 K. The GBW of 3.5 GHz was archived with a relatively thick film (a typical film thickness for NbN HEB mixers is 3–5 nm).

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