Mixing with Y-Ba-Cu-O Josephson Junctions Fabricated with Focused Helium Ion Beam Irradiation

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Current state-of-the-art mixers with the best reported sensitivities are superconductor-insulator-superconductor (SIS) receivers and hot-electron bolometers (HEB) [1]. Both have proven to be successful in the practicality of space flight missions. However, SIS and HEB mixers have their limitations. SIS mixers demonstrate nearly quantum limited sensitivity up to approximately 700 GHz, but then exhibit a reduction in sensitivity above 1 THz [1]. The use of HEBs are therefore utilized for operations above 1 THz, however they experience noise temperatures of approximately 10 times the quantum limit. High transition-temperature superconductor (HTS) Josephson junction (JJ) mixers have the potential for high frequency operation due to their larger superconducting energy gaps, when compared to low temperature superconductors, that are typically used in SIS receivers. HTS JJ mixers could also offer a large intermediate frequency (IF) bandwidth (10-20 GHz), low local oscillator power requirements (~100 nW), the potential for higher sensitivity at 1-2 THz, and higher temperature operation. In this work, we investigate the conversion gain of a Y-Ba-Cu-O (YBCO) focused helium ion beam Josephson junction (HI-JJ) operating as a mixer at 250 GHz.

The design of the device involves a JJ contained in a 4 μm YBCO bridge at the center of a log spiral antenna. The JJ is created with a focused helium ion beam (FHIB) which disorders oxygen in the crystal structure of YBCO, that converts the material from superconductor to insulator [2]. The FHIB technique is conducive to the THz mixer application because it allows for nano-scale junctions to be created through a trimming step with a high dose of helium ions that drives the material insulating [3]. This ultimately gives the ability to control the junction size, as well as to tune the impedance of the junction [4] to match the antenna (~70 Ω).

The current-voltage characteristics (I-V) were recorded for both the unpumped and pumped case. The junction exhibited a critical current (I_c) of approximately 0.1 mA and a normal state resistance of 11 Ω. The device was pumped with 250 GHz and the I-V curve revealed several Shapiro steps corresponding to the AC Josephson effect: $V = n\frac{h\nu}{2e}$ where n is an integer, ν is the drive frequency, and h/2e is the flux quantum. The device I-V curve and IF output power vs bias voltage was recorded with and without 250 GHz radiation for several different power levels and is shown in Fig. 1.

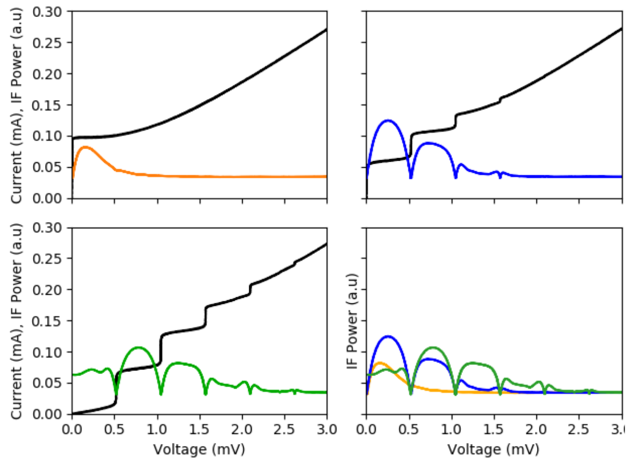

Fig. 1. I-V curves with IF power vs voltage for varying pump power at 250 GHz radiation.

To determine the conversion gain of the mixer we utilize a resistively and capacitively shunted junction (RCSJ) model to find a fit to the data to approximate the incident RF power. A time dependent current source of the form $I_{rf}Sin(\omega_{rf}t)$ is added to the RCSJ model to include the AC Josephson effect. A good fit to the pumped case of half suppression of the unpumped critical current was found with I_{rf} = 0.07 mA. From this fit we determine the conversion gain of the device is approximately -5.5 dB. This is very promising when we compare it to the performance of the detectors used on the Heterodyne Instrument for the Far Infrared (HIFI), which had conversion gains ranging from -10 dB to -4 dB. This work demonstrates the great potential and flexibility of YBCO junctions directly written with a focused helium ion beam for high frequency applications.

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