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HARMONIC GENERATION AND MIXING IN HIGH-T_C JOSEPHSON JUNCTIONS WITH TERAHERTZ BANDWIDTH

E. N. GROSSMAN, L. R. VALE, L. R. ZINK, AND K. M. EVENSON,
National Institute of Standards and Technology
325 Broadway
Boulder, CO 80303

Recently, we have developed step-edge YBCO Josephson junctions with characteristic frequencies $f_c = (2e/h)(I_c R_n)$ of up to 5 THz (where I_c and R_n are the junction's critical current and normal-state resistance) [1,2]. Our project's overall aim is to explore the capabilities of these junctions for several types of frequency translation, utilizing the junction's ability to support very high frequency currents. These include high bandwidth mixing at CO_2 laser (30 THz) and visible frequencies, low noise mixing at THz frequencies, and harmonic mixing from mm-wave up to THz frequencies.

The high frequency behavior of a Josephson junction is most directly probed through phase-locking of the internal Josephson currents to an externally applied AC signal and its harmonics (as manifested by Shapiro steps in the current-voltage characteristic). We have measured the power, frequency, and temperature dependence of the Shapiro step heights under THz frequency illumination. Our best device has shown Shapiro steps (phase-locked Josephson currents) up to the 18th harmonic of an applied 404 GHz signal. (See figure 1 below.) The Shapiro step data qualitatively fits the resistively and capacitively shunted junction (RCSJ) model .

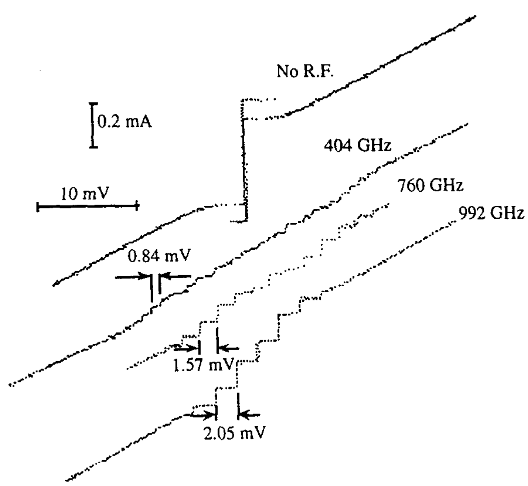

Figure 1. Current-voltage characteristics of a YBCO step-edge Josephson junction with f_c = 4.8 THz, showing Shapiro steps under illumination by far-infrared laser. The junction was coupled to the laser via a broadband, log-periodic, lithographic antenna. Operating temperature was 9 K.

We have also performed direct mixing experiments between two CO_2 lasers with frequency differences from 10 MHz to 12 GHz, and higher order mixing experiments between two CO_2 lasers and an applied microwave signal and its harmonics, with a separation of the CO_2 lasers of up to 27 GHz [3]. The CO_2 mixing data shows a clear separation between two different physical mechanisms, hot-electron mixing in the thin-film YBCO of the junction's banks, and Josephson mixing in the junction itself (see figure 2). The hot-electron mixing in the YBCO banks of the junction is directly comparable to the direct modulation experiments performed by the Moscow/Chalmers group [4]. The mixing in the Josephson junction itself is of interest because (a) it may

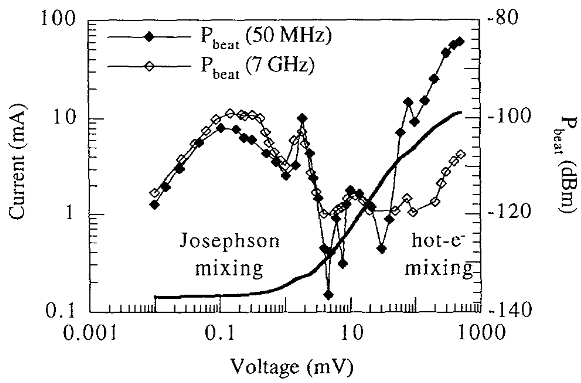

Figure 2. Bias dependence of the power in the beat note between two 30 THz CO_2 lasers, separated by 50 Mz and 7 GHz. The DC current-voltage characteristic is the solid line. The two mixing mechanisms occur in two distinct bias regimes: Josephson mixing in the junction at low biases, with positive curvature in the I-V curve, and hot electron mixing in the banks at high biases, with negative curvature in the I-V curve.

have a much higher bandwidth than hot-electron mixing in the film, and (b) it is compatible with very high order harmonic mixing. The most applicable theory for the mixing in the junction [5] was developed to describe similar high frequency mixing experiments done on point-contact junctions made from low-T_c superconductors. That theory predicts that the bandwidth of such a mixer is limited by the characteristic frequency of the junction. Hot-electron mixing in the film, on the other hand, is limited in bandwidth by the electron-phonon relaxation rate, thought to be of order 100 GHz in YBCO. Likewise the capabilities of Josephson junctions for very high-order harmonic mixing have been demonstrated with low-T_c junctions [6]. Combining the functions of harmonic generation and mixing in a single device, a high-T_c Josephson junction offers the ability to measure multi-THz frequency differences, without the neccesity of dealing with THz frequency signals directly.

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