Josephson Effect up to 1.9 THz in a Planar MgB_2 Junction with High-I_cR_n Product

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October 20, 2016 (STH45, HP118). This work presents the first low noise mixing above 1 THz using the Josephson Effect [1]. This is enabled by a planar-type ion-damage junction with an I_cR_n product of 5.2 mV. The promise of record sensitivity from the 1.4 THz cutoff of the SIS mixer [2] to the 1.9 THz benchmark is of significant importance to the astrophysics community because ionized carbon [CII] which can be identified at 1.89 THz plays a large role in the lifecycle of the interstellar medium. Observations of [CII] in our own and nearby galaxies can give invaluable insight into the largely unknown process of star formation. The large I_cR_n product of the junction is also appealing for digital circuit applications, as this product is the limiting factor in many different Josephson devices, such as SQUIDs [3] and parametric amplifiers [4]. The junctions exhibit a zero-voltage current all the way to 36 K meaning that they have further application as an intermediate temperature stage for transferring data from more complex Nb-based circuits at 4.2 K to room temperature.

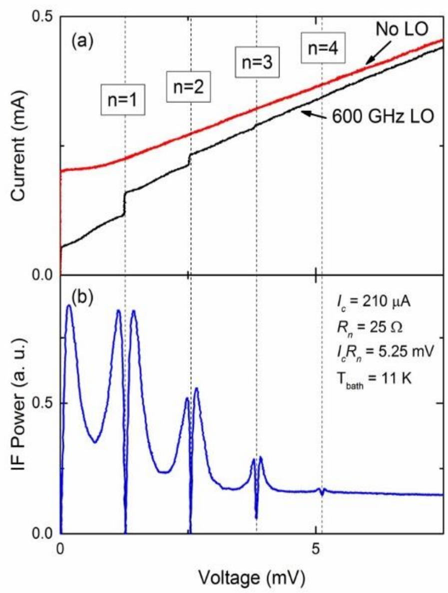

Fig. 1. (a) Current vs voltage for the junction under 600 GHz irradiation (black) and without pumping (red). (b) IF power in the same junction been irradiated at 600 GHz showing the local minima occurring at the voltage corresponding to the Shapiro steps.
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Highlighted here is research which used MgB_2 films grown by the HPCVD process to pattern micro-bridges coupled to spiral antennas. The interface between the ultra-thin film bridge and thick film antenna was unprotected and exposed to argon ion milling. The result was an SNS-like, hysteresis-free junction with I_cR_n product exceeding 5.2 mV at low temperature. The noise temperature was measured to be about 900 K at 600 GHz and around 4000 K at 1.9 THz (system losses were found later which should imply about a factor of 2 improvement in the sensitivity at 1.9 THz). The noise temperature at 600 GHz remained low up to 20 K and the IF bandwidth of the mixer was larger than the 12 GHz of the low noise amplifier, implying that the Josephson effect was indeed the mixing mechanism.

Figure 1 shows the IV curve of the junction with and without 600 GHz irradiation and (b) shows the corresponding IF power as a function of voltage. The IF power is closely related to the differential resistance and hence is very sensitive to the Shapiro steps. A feature can be seen in the IF power at n = 4 whereas the corresponding step cannot be resolved in the IV curve. In Fig. 2 (a-e), the IF power is used to show the Shapiro steps for frequencies at 90

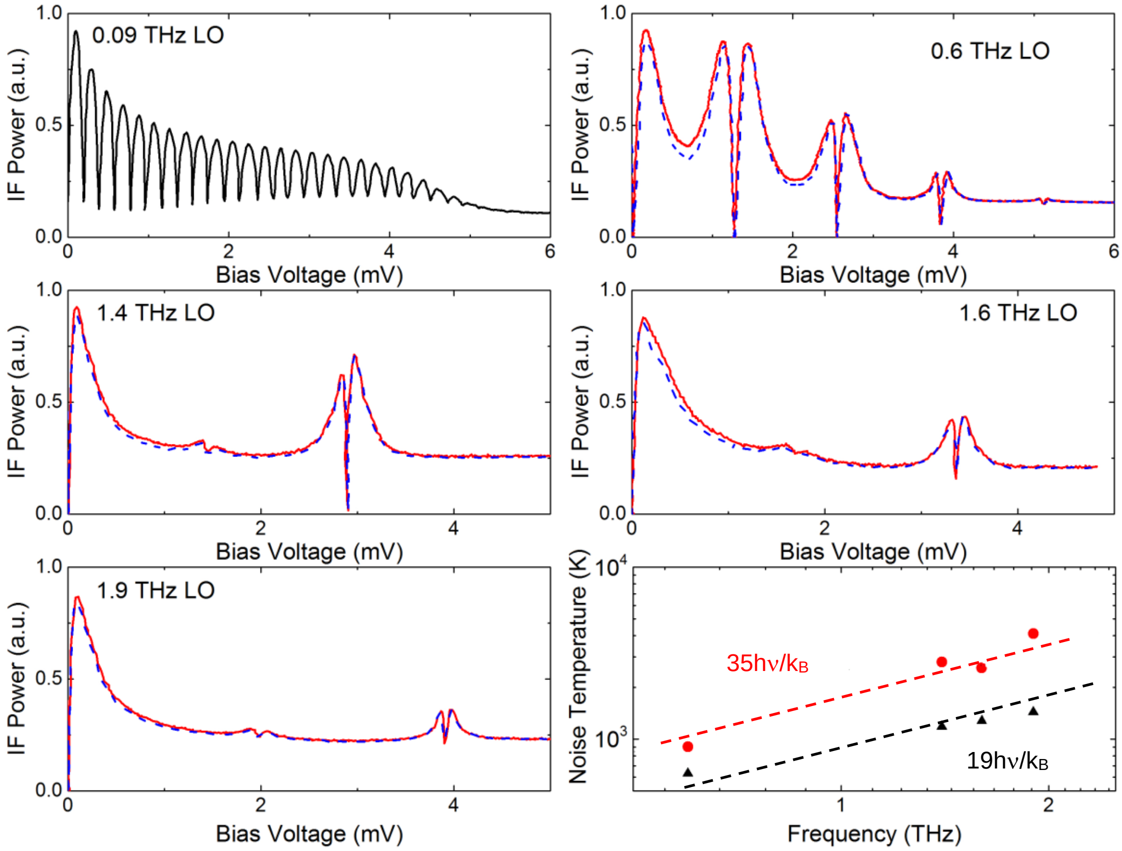

Fig. 2. (a-e) IF power as a function of voltage in the junction under different frequency irradiation from 90 GHz to 1.9 THz. Solid red line is a response to a 295K black body emitter, blue dashed line is a response to an 80K emitter. (f) Noise temperature of the Josephson receiver as a function of frequency. Red dots are uncorrected noise temperature data for the entire receiver. Black triangles are data points corrected for known optical loss in the system. Adopted from [1], with the permission of AIP Publishing.

GHz, 600 GHz, 1.4 THz, 1.6 THz, and 1.9 THz and (f) shows the noise temperature of the mixer as a function of frequency. This work describes the first practically applied Josephson effect above 1 THz in MgB_2, pointing out the immense potential of the material for numerous superconducting device applications.

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References

[1] D. Cunnane, J. H. Kawamura, N. Acharya, M. A. Wolak, X. X. Xi, and B. S. Karasik, *Appl. Phys. Lett.* **109** (No. 11), 112602 (2016). http://dx.doi.org/10.1063/1.4962634.

[2] A. Karpov, D. Miller, F. Rice, J. A. Stern, B. Bumble, H. G. LeDuc, and J. Zmuidzinas, "Low Noise 1 THz–1.4 THz Mixers Using Nb/Al-AlN/NbTiN SIS Junctions," *IEEE Trans. Appl. Supercond.* **17** (No. 2), 343-346 (2007).

[3] T. Van Duzer and C. W. Turner, *Principles of Superconductive Devices and Circuits*, Prentice Hall PTR, 2nd ed., (1999).

[4] A. A. Clerk, M. H. Devoret, S. M. Girvin, F. Marquardt, and R. J. Schoelkopf, "Introduction to quantum noise, measurement, and amplification," *Rev. Mod. Phys.* **82** (No. 2), 1155-1208 (2010).