Josephson emission from $Bi_2Sr_2CaCu_2O_{8+\delta}$ mesa structures

Borodianskyi .E.A. Krasnov V.M.

Department of Physics, Stockholm university, AlbaNova University Center, SE-106 91 Stockholm, Sweden

[*]E-mail: ievgenii.borodianskyi@fysik.su.se

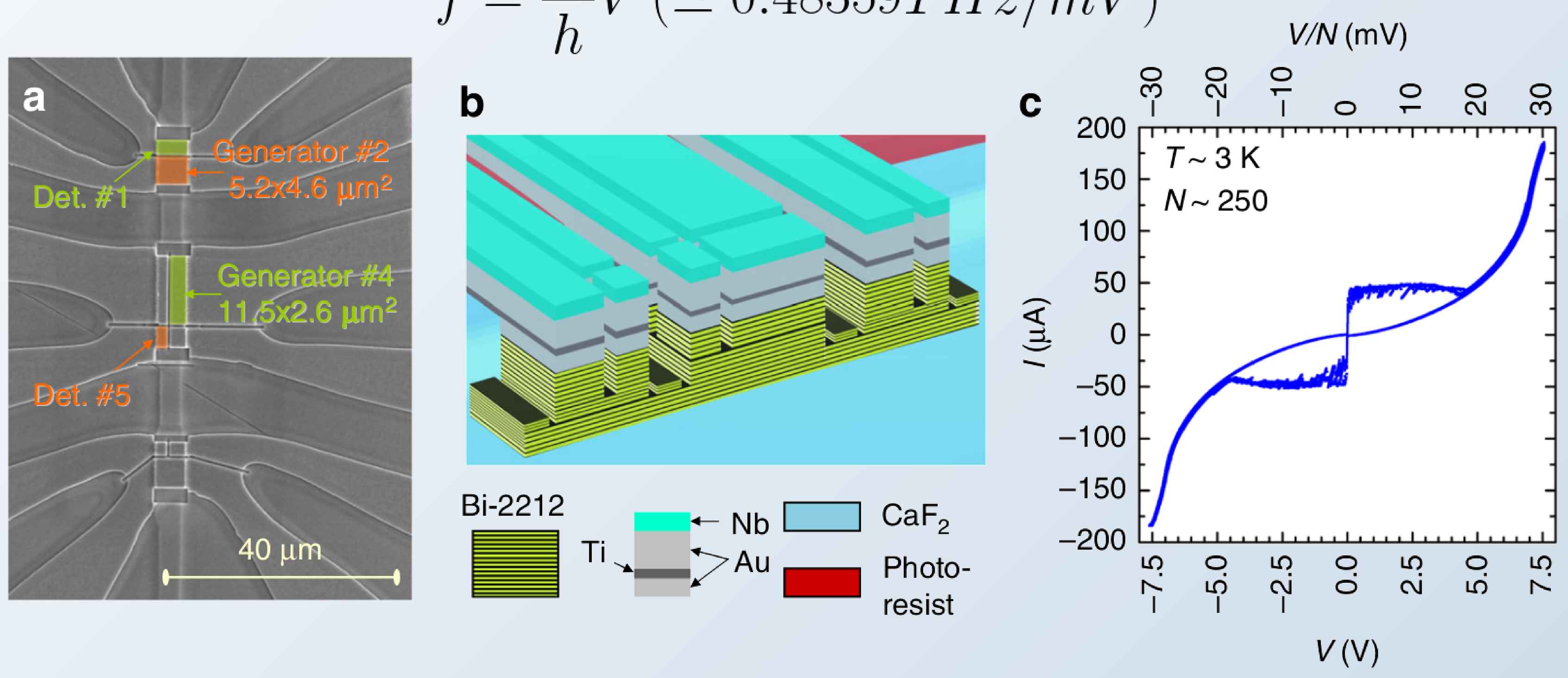
Mesa structures made of Bi2Sr2CaCu2O8+δ high-temperature superconductor represent stacks of atomic scale intrinsic Josephson junctions. They can be used for generation of highfrequency electromagnetic waves. Here we analyze Josephson emission from small-but-high mesas (with a small area, but containing many stacked junctions). We have found strong evidence for tunable terahertz emission with a good efficacy in a record high-frequency span 1–11 THz, approaching the theoretical upper limit for this superconductor. Emission maxima correspond to in-phase cavity modes in the mesas, indicating coherent superradiant nature of the emission. We conclude that terahertz emission requires a threshold number of junctions N ~ 100. The threshold behavior is not present in the classical description of stacked Josephson junctions and suggests importance of laser-like cascade amplification of the photon number in the cavity.

Sample Characteristics

Using superconductors instead of semiconductors provide an alternative technology for creation of inherently highly tunable continuous wave, norrow line-width, compact THz sources.

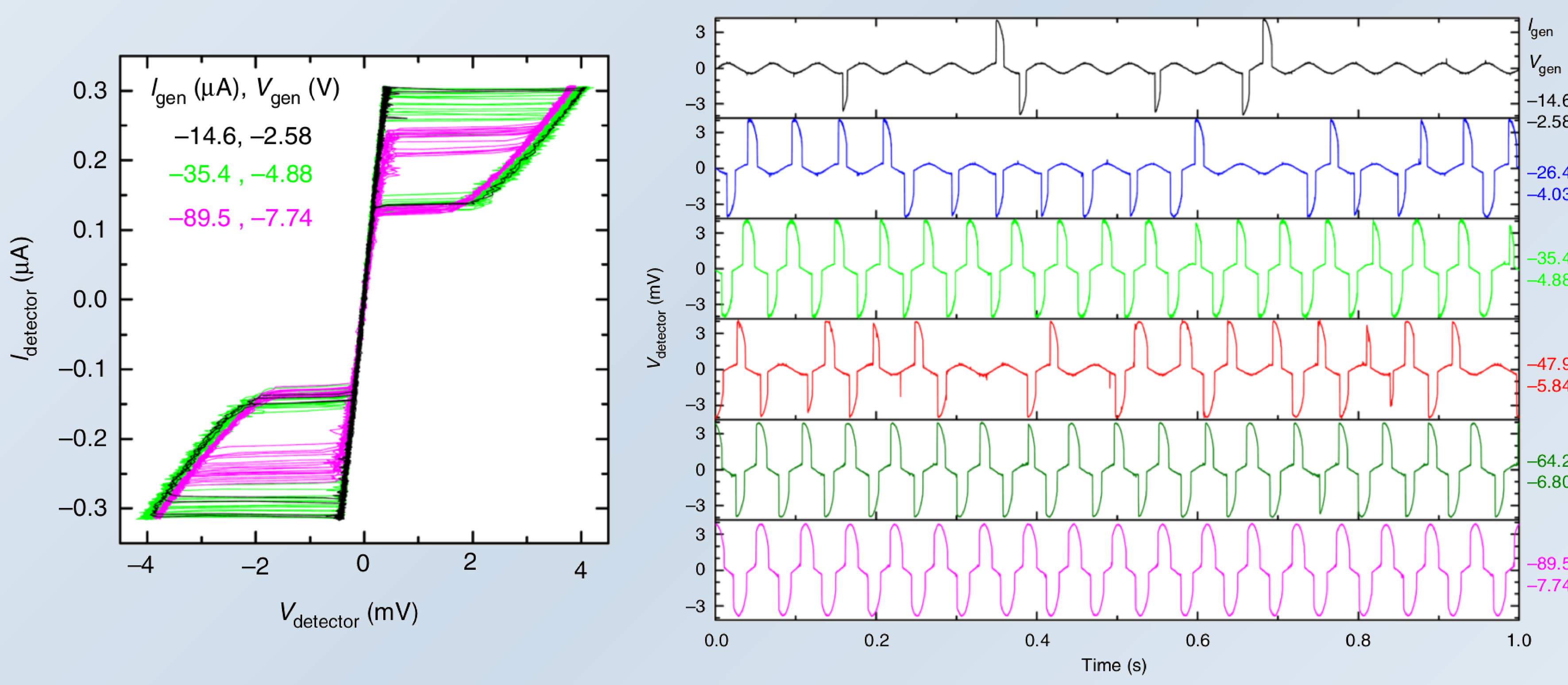
Superconducting Josephson junctions allow a direct conversion of DC-voltage into high-frequency electromagnetic oscillations with a tunable frequency.

$$f = \frac{2e}{h} V \; (\simeq 0.48359 THz/mV)$$



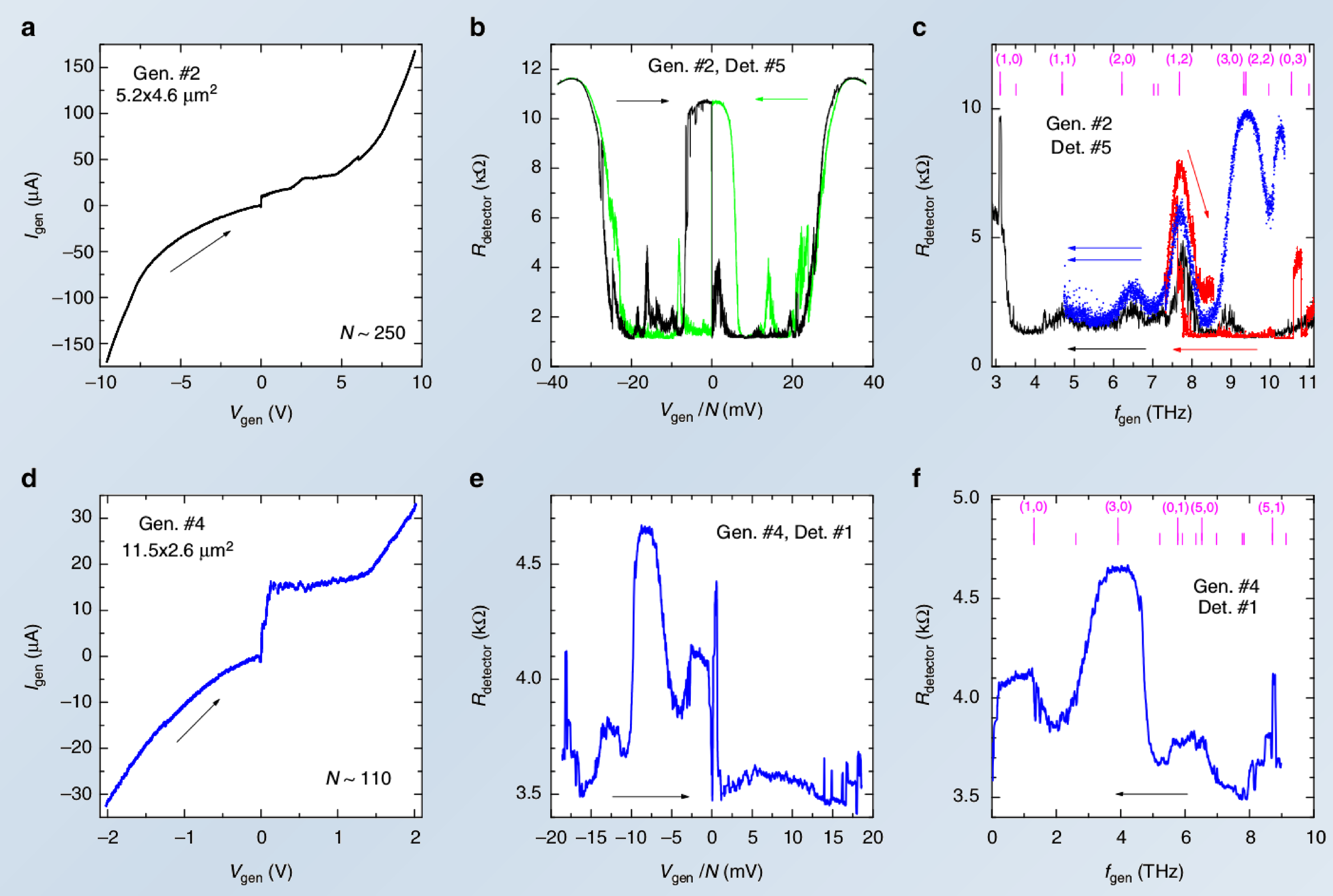
a *Scanning electron microscopy image of the studied sample. The generator and the detector mesas are indicated.* ***b*** *A three dimensional sketch of the sample.* ***c*** *Current–voltage characteristics of the generator mesa #2. The top axis shows voltage per junction. A kink at V/N= 2Δ/e ~ 30 mV represents the sum-gap singularity. It corresponds to ~15 THz upper Josephson frequency limit.*

Switching current detector



a *I–V characteristics of a top junction in the detector mesa #5 for different biases in the generator mesa #2.* ***b*** *Time dependence of the detector voltage. Different panels from top to bottom correspond to increasing negative bias in the generator. The number of voltage pulses reflect the switching probability. It is seen that the switching probability changes non-monotonously with the generator bias. The base temperature is T ~ 3 K*

Generation detection experiment 1-11 THz

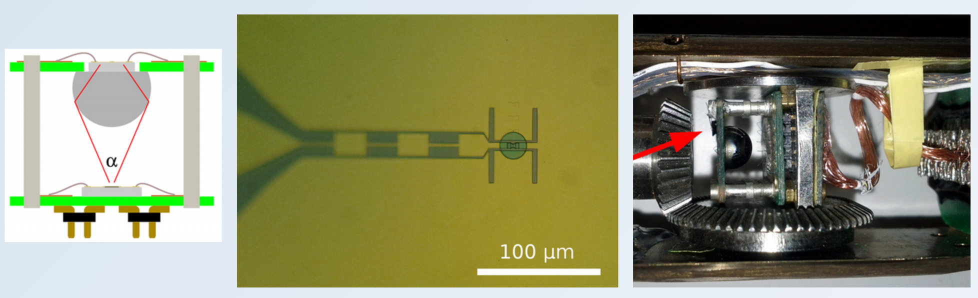


For ***a–c*** *generator #2, detector #5 and* ***d–f*** *generator #4, detector #1. The base temperature is T = 3 K.* ***a, d*** *I–V characteristics of generator mesas for bias sweep from negative to positive voltage.* ***b, e*** *Measured detector responses as a function of the generator voltage per junction. The green line in* ***b*** *represents detector response for a reverse bias sweep in the generator from positive to negative voltage.* ***c, f*** *Emission spectra: detector response vs. Josephson frequency for the falling parts of the generator I–V curves.*

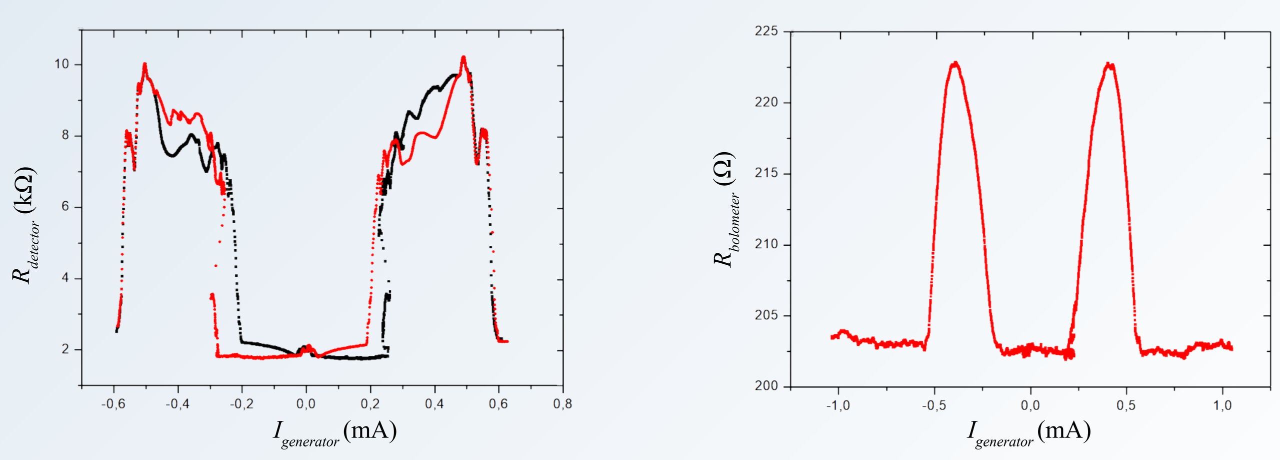
$$f(m,n) = \frac{c_1}{2}\sqrt{\frac{m^2}{L_x^2} + \frac{n^2}{L_y^2}}$$

Vertical bars on top of ***c, f*** *mark expected frequencies of strongly emitting in-phase geometrical resonances in a rectangular mesa with sizes $L_x \times L_y$ corresponding to those generators.*

Genaration detection experiment with inbuild and bolometer detector



Hot-electron bolometer mounted on hyper-hemispherical lens sketch, actual image of dual-slit antenna and system itself.*



Here compartion from two deferent ways of detection by ***left*** *by inbuild sample detector and* ***right*** *by separate bolometer.*

** Taken from Holger Motzkau PhD thesis: "High-frequency phenomena in small $Bi_2Sr_2CaCu_2O_{8+x}$ intrinsic Josephson junctions" (2015) URN: urn:nbn:se:su:diva-115582*

An order of magnitude estimation of the maximum emission power yields ~1 μW, which corresponds to an encouraging DC to AC conversion efficacy.

Thus we reported emission with a good efficacy in a broad 1–11 THz frequency range, which is record high for Josephson devices and is close to the limit set by the superconducting energy gap of the used cuprate.

Borodianskyi, E.A., Krasnov, V.M. ***Josephson emission with frequency span 1-11 THz from small $Bi_2Sr_2CaCu_2O_{8+\delta}$ mesa structures*** *(2017) Nature Communications, 8 (1), art. no. 1742 http://www.nature.com/ncomms/ doi: 10.1038/s41467-017-01888-4*

The work was supported by the European Union H2020-WIDESPREAD-05-2017-Twinning Project "SPINTECH" under grant agreement Nr. 810144