Superconducting THz sources

Josephson Junctions (JJs) offer a natural way to convert a dc voltage into high-frequency electromagnetic radiation. However, research on individual JJs and JJ-arrays in the early 1970s showed only very weak emission. Recently, intrinsic Josephson junctions (iJJs) in Bi$_2$Sr$_2$CaCu$_2$O$_8$ (BSCCO) have been shown to be promising candidates to be light-emitting devices in the THz regime, allowing frequencies up to several THz. Stacks of many hundred iJJs can be fabricated easily. Research on BSCCO THz generators stagnated in the past due to perhaps modest success in creating operating devices. In 2007 Ozyuzer et al. detected coherent radiation up to 0.85 THz from large, rectangular mesa structures on BSCCO single crystals, reviving the research in this field.[1] The term mesa in this context refers to an elevated semiconductor structure with flat top, which serves as cavity for electromagnetic standing waves, synchronizing the junctions in the stack. More than 500 junctions in the stack oscillated in phase, leading to a power of up to 0.5 $\mu$W. However, to date the actual synchronization mechanism, the spectral properties and angular dependence of the emission characteristics as well as the role of so-called hot spots in the mesas are subjects of active research.

In this lab course we study the electronic transport properties and THz emission of iJJs in a BSCCO mesa structure.

Preparation and Literature

Revise the physics of Josephson junctions as discussed in the lectures, in particular the ac- and dc Josephson effects and the RSJ model.

In long JJs and extended, planar JJs with dimensions larger than the Josephson penetration depth, the Josephson phase becomes a function of the spatial coordinates $\phi(x, y, t)$. The Josephson current flowing through a stack of JJs couples with the electromagnetic field. Due to this coupling, similarly to a single Josephson junction, electromagnetic waves, Josephson plasma waves (JPWs), can propagate either in artificial multi-stacks or in layered superconductors, such as BSCCO, which eventually gives rise to the emission of THz radiation.[2] The motion of the Josephson phase is often described by the Sine-Gordon equation, which is essential for the understanding of JPWs. A summary of the physics of extended JJs is given in Tinkham’s book [3] (page 215-224) and an introduction to THz emission in BSCCO may be found in reference [4].
Literature:


Report, Questions and Exercises

• Describe the electromagnetic state of a stack of JJs that leads to the formation of Josephson plasma waves.

• Illustrate how a THz source may be constructed from BSCCO crystals.

• Discuss the $I - V$ characteristics of the BSCCO mesa recorded at different temperatures and explain its characteristic features. What is the reason for the back-bending of the $I - V$ curves in the resistive branch?

• Determine the critical temperature, critical field and critical supercurrent of the device and estimate the number of JJs in the active stack.

• Indicate the points in the $I - V$ characteristics, where THz emission is expected. Estimate the expected frequency of the emitted radiation and compare the results to the measured THz spectra.