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A Tunable Josephson Junction Far Infrared Source*

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Abstract

We have studied radiation emitted by Nb-Nb point contact Josephson junctions at frequencies up to 30 cm^{-1} . Spectroscopic measurements on solids have been made using this source.

Radiation emitted by Josephson junctions has been observed in numerous experiments. The fact that this radiation is monochromatic at a frequency related to the bias voltage by the Josephson relation

$$hf = 2eV$$

makes the junction a candidate from which to construct a tunable narrowband source.

The above relation has been shown to be material independent and accurate to a very high precision.¹ The effect can occur at frequencies from zero up until it is quenched by either of two processes: Capacitance of the device shunting its oscillatory currents, or the destruction of superconductivity in the junction due to the photons having energy much larger than the superconducting energy gap. The energy gap is on the order of 25 cm^{-1} in niobium.

Using Nb-Nb point contact junctions, we have observed this radiation at frequencies from 2 cm^{-1} to 30 cm^{-1} , at power levels of up to 10^{-9} W . We have found the radiation to be narrowband and tunable and have made transmission measurement, on several absorption lines in crystals.

Experiments

1. The Junction

In order to achieve the low capacitance necessary at high

frequencies, we have predominantly used point contact junctions. Niobium is used because it offers the combined virtues of high (25 cm^{-1}) energy gap frequency and ease of fabrication. Point contact devices are very susceptible to mechanical and thermal disturbances. To avoid these problems, we have built the junctions solely from niobium and a glass whose thermal expansion matches that of niobium.

The junction is formed by a niobium screw pressing together, at a point, two niobium foils spaced slightly apart by glass.

The junction is current biased, and a four wire connection allows measurement of V , I and dV/dI .

2. Apparatus

a. One dewar experiments.

The majority of experiments are done in a self-contained pumped helium-3 detector cryostat with the junction and a helium-3 cooled bolometer in adjacent chambers. The bolometer is made of compensated In and Sb doped Ge, and runs at a temperature of about 0.35°K .

The niobium screw can be rotated from outside the dewar by a disengagable mechanism, so that once a desirable junction is obtained, it may be taken out of the dewar and saved for later use.

In order to synchronously detect the radiation, the junction is biased with square waves, one of whose levels is at the

desired junction current.

b. Two dewar experiments.

The spectrum of the radiation may be analyzed by bringing the radiation out of a source dewar via $\frac{1}{2}$ " diam. light pipe and passing it through a lamellar grating interferometer. It then passes into another dewar to a He-3 cooled bolometer. The interferometer is suitable for operation in the 2 cm^{-1} to 100 cm^{-1} frequency range, and conventional Fourier transform spectroscopy is performed using an on-line PDP-11 computer.

c. Spectroscopy using the junction as a source has been performed by placing the junction, a rotator containing the samples to be analyzed, and a detector in line. Transmitted radiation vs. junction voltage is recorded and can be digitized and normalized using the computer.

Results

As is typical of point contact devices, the junctions display a wide variety of properties. Critical current and normal state conductance vary more or less monotonically with the pressure on the point. Resistances of less than 1 ohm and critical currents of at least several mA work best. Most junctions display, on their V-I curves, step structure, some of which can be associated with cavity resonances caused by surrounding structures.

The step widths are generally characteristic of not very high Q cavities. Hysteresis and switching are also observed, especially at lower temperatures.

In those junctions which emit measurable radiation only when biased on steps, the radiation has the properties of Josephson radiation coupling to a cavity. Most junctions emit radiation at all frequencies (bias voltages) in their active range, the intensity being a not very smooth function of frequency, due to the step structure.

Spectrum analysis reveals the radiation to be monochromatic to within the resolution of the interferometer, and at the frequency predicted by the Josephson relation. As expected, there is occasionally some harmonic content. The power level is typical of those measured by others, about 10^{-9} W.

Line shapes of absorption lines in KBr:Li at 18 cm^{-1} , in CsI:Tl at 14 cm^{-1} and in MnF_2 at 8.7 cm^{-1} are essentially the same as those measured with the interferometer containing a conventional mercury arc source.

References

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