High Resolution X-Ray Detectors with Superconducting Tunnel Junctions (SIS and NIS)

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At the Technical University of Munich aluminum superconducting tunnel junctions (Al-STJs) [1,2] are developed as a device for high resolution X-ray spectroscopy. Al-STJs consist of two superconducting aluminum layers that are separated by a thin dielectric tunneling barrier. Cooper pairs are broken up by the absorption of energy, giving rise to detectable currents across the tunneling barrier. The absorption of energy in both the top and the bottom layer can be detected. Al-STJs can either be used as a detector themselves or as a read out device for superconducting absorber films.

An energy resolution of 12 eV (FWHM) was obtained by Al-STJs at an X-ray energy of 5.9 keV [3], what is the best result obtained with STJs at this energy so far. The improvement in resolution is attributed to the introduction of a metallic buffer layer underneath the junction. The buffer layer is separated from the STJ by a thin polymeric insulation layer with low X-ray absorption efficiency. After X-ray absorption in the buffer layer, the deposited energy thermalizes very fast, thus the number of emitted phonons able to break up Cooper pairs in the STJ's aluminum film is reduced dramatically.

Fluorescence lines both from the buffer and the substrate have been used to check the linearity of Al-STJs in the energy range between 1.74 keV and 6.49 keV. Only small deviations from linearity have been observed, giving recombination rates that are by far not sufficient to explain the energy resolution's deviation from the theoretical limit. Pulse shape analysis was used to separate events in the top and the bottom layer of the Al-STJ and allowed to determine the range of low energy photoelectrons in aluminum.

During the last year, Al-STJs have been integrated into a mobile adiabatic demagnetization refrigerator containing very thin light blocking windows allowing for the observation of external X-ray sources. This cryostat was used to characterize Al-STJs by synchrotron radiation at the electron storage rings BESSY 1 and BESSY 2 at Berlin. Both the cryostat and the bias point could be stabilized for several hours. Only small deviations from linearity could be found in the energy range between 200 eV and 2 keV. An energy resolution of about 20 eV (FWHM) could be reached. A linear behavior is found for the degradation of the energy resolution, strongly indicating spatial non-uniformity or short time instabilities in the bias point. At X-ray energies below the aluminum absorption edge the rate of events with reduced pulse height increases strongly, showing that substrate events are still existent.

Two drawbacks of tunneling junctions as X-ray detectors are the low absorption efficiency in the layers of the junction and the fact that absorption in different layers causes different signal heights. Both could recently be overcome, by introducing an electrically insulated lead absorber onto the tunneling junction. The lead film has a thickness of more than 1μm. The absorption efficiency is high up to energies of around 8 keV. The electrical insulation is necessary to avoid changes in the gap structure of the superconducting aluminum, what could result in a reduction of the signal currents. Thus, the energy couples into the junctions only via phonons. It could be shown that if the set up is put onto a thin membrane substrate one can achieve a very high energy resolution of about 12 eV FWHM at 6 keV.

Furthermore, the TUM group has recently started the development of Normalmetal-Insulator-Superconductor (NIS) tunnel junctions as X-ray detectors. NIS junctions are similar to SIS junctions, but there are no Josephson effects. Therefore NIS junctions do not need a magnetic field for their operation. An additional advantage is the high X-ray absorption efficiency in copper used for the normal metal of the junction and that absorption in the second superconducting metallayer does not cause signals. Besides their use as detectors NIS junctions are also discussed as microcoolers. This is due to the fact that under certain conditions, the bias current transfers heat from the normal metal into the superconductor.

The NIS junctions consist of a (2-3) k$\mathring{A}$ thick Copper film and a (2-6) k$\mathring{A}$ thick superconducting aluminum film separated by a thin tunneling barrier. The tunneling barrier is formed by oxidation of the aluminum film at atmosphere over (2-4) minutes. The typical tunneling area is 0.1 x 0.1 mm^2. Using SQUID read-out several NIS tunnel junctions were used to detect the characteristic X-ray radiation of ^{55}Mn. In the first measurements a line width of about 135 eV (FWHM) was achieved. However, the spectra are dominated by X-ray absorption in substrate and wires.

During detector operation pulses were measured, which showed two decay time constants. This is a first experimental hint to the correctness of a model which interprets these pulse shapes as a consequence of a decelerated reaction of the temperature of the superconducting electrode to temperature variations of the normal metal electrode. The understanding of these processes may allow further optimization of NIS junctions, both as detectors and as coolers.

References

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