A High Resolution X-Ray Detector based on Superconducting Tunnel Junctions

M. Huber, A. Rüdig, J. Jochum, G. Angloher, and F. v. Feilitzsch
Physik Department E15, TU München, 85747 Garching, Germany

Aluminum Superconducting Tunnel Junctions (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 a detectable current across the tunneling barrier. The deposition of energy in both the top and the bottom layer can be detected. Al-STJs can either be used as detectors themselves or as read out devices for superconducting absorber films.

At Technische Universität München Al-STJs are developed as a device for high resolution X-ray spectroscopy. The best energy resolution obtained so far by single Al-STJs at an X-ray energy of 5.9 keV is 12.4 eV (FWHM) [1,2]. Major drawbacks of Al-STJs as X-ray detectors are the low absorption efficiency in the electrodes of the junction and the fact that absorption in different electrodes causes different signal heights. These disadvantages could be overcome recently by introducing an electrically insulated Pb absorber onto the tunnel junction.

The Pb film typically has a thickness of about 1.3 μm and is isolated from the tunnel junction by a naturally grown Al_xO_y layer on the surface of the Al STJ. The absorption efficiency is about 50% at X-ray energies around 6 keV and higher than 99.9% below 1 keV. The electrical insulation is necessary to avoid changes in the gap structure of the superconducting Al, what could result in a reduction of the signal currents. Thus, the energy couples into the junction via phonons only. Furthermore, the lack of electrical contact between absorber and Al-STJ allows a homogenization of electronical excitations (quasiparticles) in the absorber which results in a homogeneous energy transfer into the Al-STJ. This reduces the influence of spatial inhomogenities on the detector's energy resolution.

The homogenization of excitations in the absorber occurs within the lifetime of quasiparticle in Pb. This lifetime leads to an increase of the current signal rise time which allows the discrimination of events related to X-ray absorption in the Pb absorber against events caused by absorption in other parts of the detector (e.g. membrane, Al-STJ electrodes). Thus, a further reduction of detector artefacts and background in the pulse height spectrum could be achieved via pulse shape discrimination.

By fabricating the detector on a 300 nm thin Si_3N_4-membrane, signal degeneration caused by phonon losses into the substrate was avoided.

A high energy resolution of 10.8 eV (FWHM) at an X-ray energy of 5.9 keV was achieved by reading out a $90x90x1.3\mu m^3$ sized Pb absorber with an Al-STJ ($100x100\mu m^2$) on a membrane.

The drawback of the Pb absorbers is their degeneration over time. Latest measurements indicate that this degeneration is caused by the oxidation of Pb during contact with air. It can be avoided by the deposition of a $\approx 1.3\mu$m thick SiO layer onto the absorber, which, however, leads to a reduced energy resolution of about 20 eV (FWHM) at 6 keV.

Further calibration and linearity tests of the Al-STJ detectors are planned to be carried out at the Synchrotron BESSY (Berlin) in the year 2002.

References

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