High Resolution X-Ray Detectors with Superconducting Tunnel Junctions

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At the Technical University of Munich aluminum superconducting tunnel junctions (Al-STJs) 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, what is the best result obtained with STJs at this X-ray 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. Energy of X-ray absorption in the buffer layer and phonons of X-ray absorption in the substrate thermalize very fast in the buffer layer. Thus, the emitted phonons reaching the STJ have mainly been converted into energies below $2\Delta_{Al}$, where Δ_{Al} is the energy gap of aluminum. As a consequence, the number of phonons able to break up Cooper pairs in the STJ's aluminum electrodes is reduced dramatically, leading to a reduced signal background.

The linearity of the Al-STJs was checked 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. From pulse shape analysis it can be deduced if the energy was deposited in the top or bottom electrode of the tunnel junction, or if it was shared between the two electrodes. The range of low energy photoelectrons in aluminum layers could be determined by the distribution of these events with shared energy deposition.

Major drawbacks of Al-STJs as X-ray detectors are the low absorption efficiency in the electrodes of the junction, the non-linearity between energy deposition and resulting pulse height and the fact that absorption in different electrodes causes different signal heights. These three disadvantages could recently be overcome by introducing an electrically insulated lead absorber onto the tunnel junction.

The lead 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 aluminum junction. 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 aluminum, what could result in a reduction of the signal currents. Thus, the energy couples into the junction only via phonons. By fabricating the detector on a 300 nm thin Si_3N_4-membrane, signal degeneration caused by phonon losses into the substrate could be avoided. For the same reason, the nonlinearity of the tunnel junction is reduced significantly to a number consistent with zero.

Reading out a lead absorber with an Al-STJ on a membrane, again the high energy resolution of 12 eV FWHM at an X-ray energy of 5.9 keV was achieved.

The drawback of the lead absorbers is their degeneration during thermal cycling. This degeneration can be avoided by the deposition of a SiO layer onto the absorber, which, however, leads to a reduced energy resolution of about 20 eV (FWHM) at 6 keV.

References

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