Cryogenic Detector Development at TUM, E15 ◇

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One goal is the application of cryogenic detectors in experiments for the search for dark matter candidates as well as X-ray spectroscopy, search for neutrino masses and solar neutrino detection. Attractive near-future experiments encompass applications in X-ray astronomy and the detection of non ionizing events via recoil measurements by phonon spectroscopy.

Many experiments would benefit from improved detection techniques. "Cryogenic" detectors exploit effects occurring only at low temperatures. In the case of superconductors, a gap occurs in the exitation spectrum for single electrons below a critical temperature T_c. This gap energy is smaller by three or four orders of magnitude compared to a standard semiconducting detector. By consequence, energy resolution and threshold can be improved by at least one order of magnitude.

Our group is involved in the CRESST Experiment (Cryogenic Rare Event Search with Superconducting Thermometers), a search for dark matter candidates via detection of nuclear recoils [1]. We have been developing massive cryogenic detectors which use a superconducting phase transition thermometer evaporated directly on a dielectric crystal. The energy deposited in the crystal by a single particle interaction is measured via the resulting temperature rise in the thermometer. The device is operated in the superconducting-to-normal transition of the thermometer, where a small temperature rise ΔT of the thermometer leads to a relatively large rise ΔR of its resistance. For a good temperature resolution a steep transition is required. A low operating temperature increases the size of the signal but limits the choice of superconductor. We need critical temperatures still accessible with commercial ^{3}He/^{4}He dilution refrigerators. These requirements can be met by films of pure tungsten and by films of iridium overlaid with gold using the proximity effect to reduce the T_c of the combination below that of pure Iridium(T_c=112 mK). Detectors made with W and Ir-Au thermometers on 32g sapphire crystals have achieved comparable resolutions for 6 keV X-rays (160 eV and 210 eV FWHM, respectively). Ir-Au thermometers have the advantage of adjustable operating temperatures between 20 mK and 100 mK, allowing for more flexiblility in the choice of the cryogenic equipment. For reproducible fabrication of these Ir-Au films the evaporation system has been extensively modified. Including the use of a new cleaning procedure [2] films with transition temperatures down to 27 mK with transition widths of < 1 mK have been fabricated.

Not only for the purpose of X-ray detection we develop a detector based on a superconducting tantalum absorber film in combination with aluminium Superconducting Tunnel Junctions (STJs) as readout elements for excess quasiparticles due to X-ray absorption events. The crystalline quality of the absorber film is very important to allow excess quasiparticles, excited by energy deposition, to diffuse in regions close to the STJ, where they lead to an increase of the tunneling current. Experiments performed 1995 have shown, that it is possible to grow epitaxial tantalum layers of high crystalline quality in our UHV equipment. RRR measurments showed values as high as RRR=88 [3], which equals a mean free path for electrons of 7.6 k at Helium temperature. RHEED, XRD and RBS/Channeling data showed epitaxial growth and high crystalline quality of the evaporated films. For an X-ray detector, both STJ and absober film have to be optimized. A new etching process has been applied [4] to form aluminium STJs out of the evaporated metal layers by methods of photolithography and reactive ion etching. New methods of contact wiring have been successfully developped [5]. With such a detector an energy resolution of $\Delta E \approx 85$ eV (FWHM) for 5.89 keV X-ray events underneath one STJ could be achieved. While further optimizing our devices, it was shown [6], that there is, under certain conditions, a contribution to the total tunnel current in the STJ, that yields a current flow opposite to the applied bias voltage, thus decreasing the total tunneled charge. Depending on the bias point at the I-V characteristic of the STJ, these contributions have been shown [6] to agree with the theoretically expected amount, predicted for a STJ with proximity modified tunnel electrodes. Furthermore an energy resolution of $\Delta E \approx 59$ eV (FWHM) for 1.49 keV X-rays could be demonstrated [6].

References

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