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Section A

Fabrication of tunnel junctions on thick X-ray absorbing substrates of Nb and Ta

A.W. Hamster[a,*], E. Ferraro[a], D.J. Adelerhof[a], G.C.S. Brons[a], J. Flokstra[a], H. Rogalla[a], M.P. Bruijn[b], F. Kiewiet[b], I.J.E. Schoofs[b], O.J. Luiten[b], P.A.J. de Korte[b]

[a] *University of Twente, Dep. of Applied Physcis, P.O. Box 217, 7500 AE Enschede, Netherlands*
[b] *SRON Space Research Organization Netherlands, Utrecht, Netherlands*

Abstract

X-ray detectors based on absorber–junction combinations can combine a large detector area with position resolution and good energy resolution. We plan to use a thick, single crystal Nb or Ta absorber with readout tunnel junctions integrated on top as our next generation X-ray detector. The thickness of the absorber should ensure detection of more than 90% of the impinging photons. Special points of attention in the fabrication of this new detector, like surface preparation, the formation of contacts, and handling of the bulk absorber during the fabrication process are discussed.

1. Introduction

The absorption efficiency of X-ray photon detectors depends on the thickness and atomic number of the absorber material. In superconducting tunnel junction detectors made by thin film technology, the thickness of the absorber is usually well below one micrometer, while the characteristic absorption depth for 10 keV X-ray photons is about 14 and 3 micrometers for absorbers of Nb and Ta, respectively. Consequently, a large part of the incoming photons will pass the detector without being absorbed. Our goal is to fabricate an X-ray detector based on a large, single crystal, superconducting absorber of Nb or Ta, with a thickness well in excess of the characteristic absorption depth. The excess quasiparticles excited after photon absorption will be detected by superconducting tunnel junctions fabricated on top of the thick absorber. A concept of such a detector has been presented in Ref. [1]. In this paper, new fabrication issues related to this detector configuration are discussed.

2. Fabrication of absorber–junction detectors

A schematic overview of the absorber–junction combination that is being studied is shown in Fig. 1. During the development stage, the Nb or Ta absorber can be a single crystal, a foil or a thick layer deposited on a small Si substrate. In the ultimate detector, a single crystal of approximately $1 \times 1\ \mathrm{cm}^2$ and a thickness of 10–30 μm will be used. On top of the thick absorber, tunnel junctions of about $10^4\ \mu\mathrm{m}^2$ based on Nb/Al, AlO_x/Al/Nb or Ta/Al, AlO_x/Al/Nb multilayers are made. Ultimately, this multilayer will contain quasiparticle traps of Ta and/or Al with larger lateral dimensions than the tunnel barrier in order to optimize the volume ratios between the absorber and the (double) trap. The insulation consists of SiO or SiO_2. Contact pads for wire bonding are located on top of the absorber as well.

Special points of attention in the fabrication process are indicated by A to E in Fig. 1. The interface denoted by A should be clean and smooth. Metallic oxides or impurities may form unwanted traps, while a rough absorber substrate could impede the fabrication of high quality tunnel barriers. We are investigating three different surface prepara-

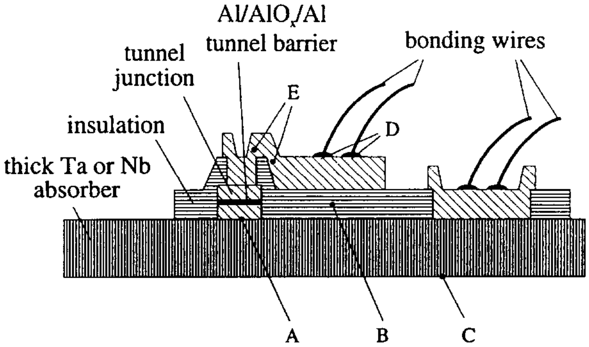

Fig. 1. Schematic overview of tunnel junctions fabricated on top of a thick absorber. Special points of attention in the fabrication process are indicated by A to E.

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[*] Corresponding author. Tel. +31 53 893841, fax +31 53 332371, e-mail hsr@tn.utwente.nl.

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tion techniques: mechanical polishing, chemical etching and electropolishing. Nb and Ta slices with a thickness of 0.5 mm, cut from single crystal rods by spark erosion, have been ground and polished down to a thickness of 0.2 mm. The final step was done with 50 nm Al_2O_3 polish. At some spots, an rms surface roughness of 1–2 nm has been obtained over areas of up to 80 μm^2, as determined by AFM. This compares well with the surface roughness of sputter deposited Nb thin films. However, the density of terraces, grains and scratches may yet be too large to facilitate high quality junctions with reasonable areas. The effect of mechanically induced inclusions and lattice deformations on the surface properties of the crystal is still to be investigated. Chemical techniques like etching and electropolishing are expected to produce better surface properties with respect to purity and crystal structure. Chemical etching in a mixture of 56 vol.% H_2SO_4 (96%), 22% HNO_3 (65%), and 22% HF (40%) can be used to remove the top layer of Nb or Ta samples. Electropolishing may both be used for removal of contaminated or deformed top layers and for polishing. This technique is described in Ref. [2]. In our setup, the Nb or Ta sample is glued to a copper rod with silver paint. The copper rod is protected from the electrolyte by teflon. A gold or platinum wire is used as the cathode. At present, two electrolytes seem promising for electropolishing: a mixture of 50 vol.% lactic acid (90%), 25% H_2SO_4 (96%), and 25% HF (40%), or a mixture of 10 vol.% HF (50%) with 90% H_2SO_4 (96%). In Fig. 2, a characteristic I–V curve of a 350 μm thick Nb foil of 1 cm^2 in an electrolyte of HF and H_2SO_4 is shown. At voltages below 3 V, Nb is etched. At about 3 V, the current becomes unstable and switches between the two solid traces of Fig. 2. The optimum bias voltage for electropolishing is at about 9 V, at the horizontal part of the I–V curve. The current density at this voltage is typically 100–150 mA/cm^2. The bias voltage depends on the used electrolyte and on the contact between the sample and the Cu rod. After electropolishing of commercial Nb or Ta rolled foil with a thickness of 125 or 250 μm, the surface looks bright and smooth, but not yet mirror-like. Under the optical microscope, a grain-like surface morphology is observed, with flat grain surfaces, inter-grain trenches and small pits. This may be related to the limited foil purity of 99.9% or stress in the surface of the foil induced during rolling. In that case, electropolishing of single crystals should give better results. Generally, the smoothness of a Nb or Ta foil can be improved by a factor of 3, using electropolishing.

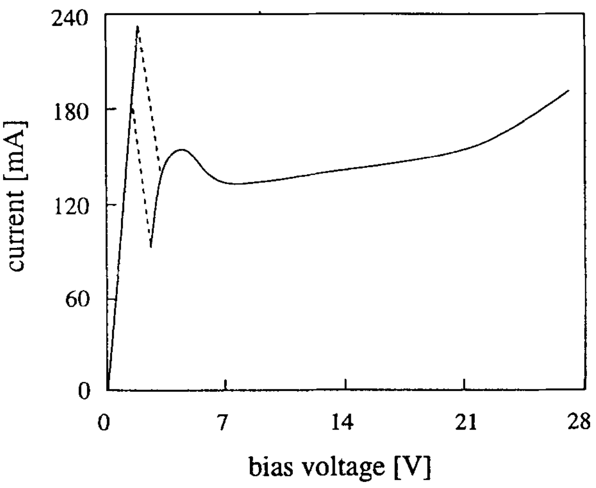

Fig. 2. Typical, voltage biased, I–V curve of a Nb foil of 1 cm^2 immersed in an electrolyte for electropolishing consisting of 10 vol.% HF (50%) and 90 vol.% H_2SO_4 (96%). Electropolishing occurs at the horizontal plateau at about 9 V.

The insulating layer indicated in Fig. 1 by B has to be thick enough to prevent shorts between the relatively large contact pads and the absorber. We found that 400 nm of evaporated SiO or 600 nm of sputtered SiO_2 is sufficient to insulate contact pads of $500 \times 700\ \mu m^2$. In the ultimate detector, the surface of the absorber (C) has to be passivated to prevent the formation of traps by oxidation, especially in case of Nb. This could for instance be done by nitridization, after definition of the dimensions of the absorber. Wire bonding (D), does not appear to pose any serious problems. Aluminum wires have been bonded using the normal bonding parameters, without causing shorts between the pad and the underlying Nb. Good step coverage (E) is achieved for thicknesses of the wiring layer equal to or larger than the insulation layer.

A practical problem in the fabrication process could be the handling of the ultimate absorber, a thin slice of Nb or Ta single crystal with a thickness of only 10–30 μm and an area of about 1 cm^2. Therefore, we plan to use relatively thick, rigid slices during junction fabrication. These slices can be glued to a suitable substrate, or be used as a substrate themselves. After fabrication, the back side will be etched back, to obtain the proper thickness. Back-etching can for instance be done by electropolishing or (reactive) plasma etching.

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