Impact of Electrical Contacts Design and Materials on the Stability of Ti Superconducting Transition Shape

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Abstract The South Pole Telescope SPT-3G camera utilizes Ti/Au Transition Edge Sensors (TESs). A key requirements for these sensors is reproducibility and long-term stability of the superconducting (SC) transitions. Here we discuss the impact of electrical contacts design and materials on the shape of the SC transitions. Using SEM (Scanning Electron Microscope), AFM (Atomic Force Microscope) and optical DIC (Differential Interference Contrast) microscopy we observed the presence of unexpected defects of morphological nature on the titanium surface and their evolution in time in proximity to Nb contacts. We found direct correlation between the variations of the morphology and the SC transition shape. Experiments with different diffusion barriers between TES and Nb leads were performed to clarify the origin of this problem. We have demonstrated that the reproducibility of superconducting transitions can be significantly improved by preventing diffusion processes in the TES-leads contact areas.

Keywords Transition Edge Sensor, bolometer, Ti films, diffusion

1 Introduction

Titanium is one of the few elemental superconductors suitable for TESs, but the properties of Ti films are very sensitive to impurities, defects, and other structural characteristics [1,2]. Such factors as film deposition conditions [3], and interaction with the substrate [4] and other materials[5] during fabrication and operation can significantly change the film properties and SC transition shape. Sharp, stable SC transitions are a critical requirement for the 16,000 TESs in the South Pole Telescope SPT-3G camera [6], so we have investigated the impact of electrical contact design and materials on the SC transition shape.

2 Experiments and discussion

Design and fabrication details for SPT-3G detectors are given in [7,8]. The TESs are 200 nm Ti (99.9992 wt %), covered with a 20 nm Au (99.99 wt %) passivation layer. The Ti and Au films were deposited at room temperature, under a single vacuum, in a confocal DC magnetron sputtering system[9]. Before deposition, the base pressure of the system was lower than 2x10-8 Torr. The TES geometry and Nb (99.99% wt %) wires were defined using lift-off processes. Low power (25W) Ar plasma cleaning of the TES-leads contact zone was carried out prior to Nb deposition to provide a reliable electrical contact. Preliminary testing of Ti/Au bilayers and single TESs demonstrated good repeatability of the SC transition and critical temperature (Tc). However, multistep processing of large **6”** detector arrays revealed substantial variations in the transition shape due to heating during some of the process steps, and also with changes in the intensity of plasma cleaning of the TES-leads contact area. Moreover, it was found that an initially smooth TES surface had unexpected morphological defects after subsequent fabrication steps. Utilizing AFM measurements, we detected local ˜10% thickenings on the TES surface (Fig.1).

The observed localized increase in film thickness is presumably caused by the internal stresses coming from impurity atoms dissolved in the film and adhesive forces between the film and the substrate. Redistribution of these impurities, caused by diffusion processes, changes local values of stress and surface morphology. Similar morphological features are typical for films with good adhesion properties when diffusion processes lead to anisotropic lattice or grain boundary expansion. In this case, in-plane expansion is suppressed by the metal-substrate interaction, but the film is free to expand in the direction normal to the film

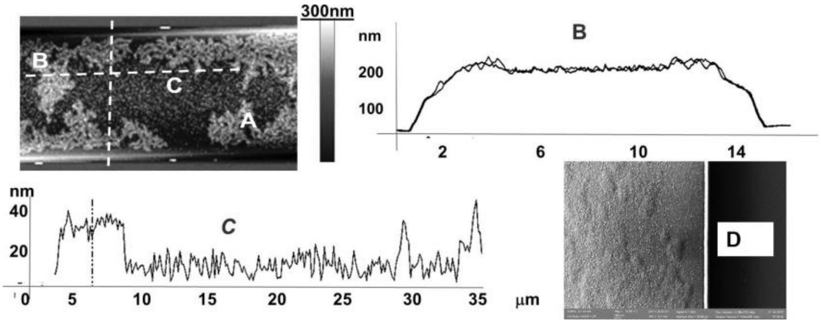

Fig. 1 The defects on the TES surface following fabrication were characterized via AFM and SEM imaging: A) AFM image showing localized swelling of a TES, B) and C) AFM height profiles showing the 10% thickness increase of the TES, and D) surface roughness seen in an angled SEM image

plane. Local variations in impurity concentration change the SC properties of the film and could explain the unusual shapes of the SC transitions observed in some samples. We found that there is a direct correlation between variations in TES surface morphology and SC transition shape (Fig.2). Generally, the Au passivation layer prevents interaction between the Ti film and ambient or materials in contact. However, the Au layer can be partially or completely removed from the TES-leads contact area during plasma cleaning. As a result, pure Ti can be in contact with Nb over an area that depends on the amount of plasma cleaning and on the slope of the TES edges. We observed a strong dependence of SC transition shape on the intensity of plasma cleaning.

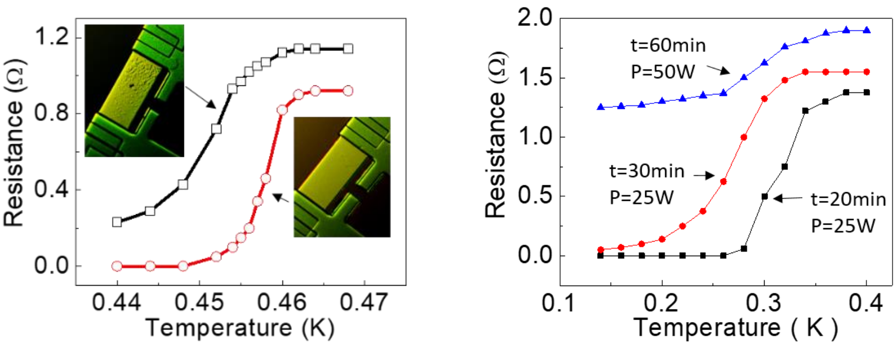

Fig. 2 SC transitions of TESs from the same wafer. Correlation between SC transition and surface morphology (left), dependence of SC transition on the intensity (time and power) of plasma cleaning of the TES-leads contact area (right). Images were taken with DIC microscopy.

In order to clarify the origin of the problem, we prepared test samples that excluded heating and any contact with chemicals. The test samples were patterned using metal shadow masks (Fig.3). As can be seen in Fig. 3, a direct Ti-Nb contact initiates a non-steady-state diffusion process which can be explained by migration of the impurities dissolved in the Nb layer towards the Ti layer. The relatively fast process can be interpreted as a grain boundary diffusion, which is the dominating atomic transport mechanism at low temperatures.

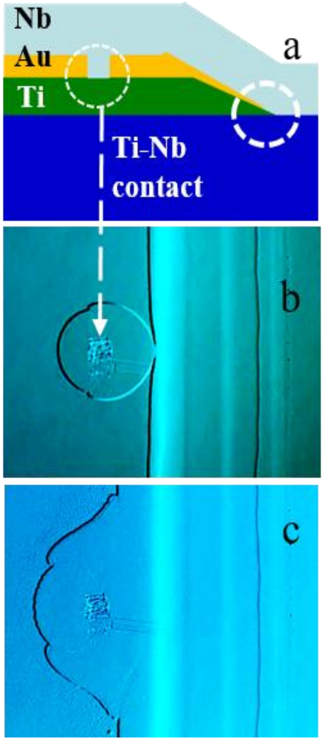

Fig. 3 Thickenings in proximity to Nb-Ti contact, a) cross section of the sample showing Nb-Ti contacts points , b) optical image *(top view)* taken one-day after sample deposition, and c) optical image taken two weeks after sample deposition

The Ti-Nb contact problem was noticed earlier in [8,10,11]. Both Ti and Nb are getter materi- als, and during fabrication processes different active gas molecules (such as H2, O2, H2 O, CO, CO2, etc.) can be absorbed or dissolved in the films. If the concentration of impurities in the Ti and Nb layers is different, migration of the impurities can take place.

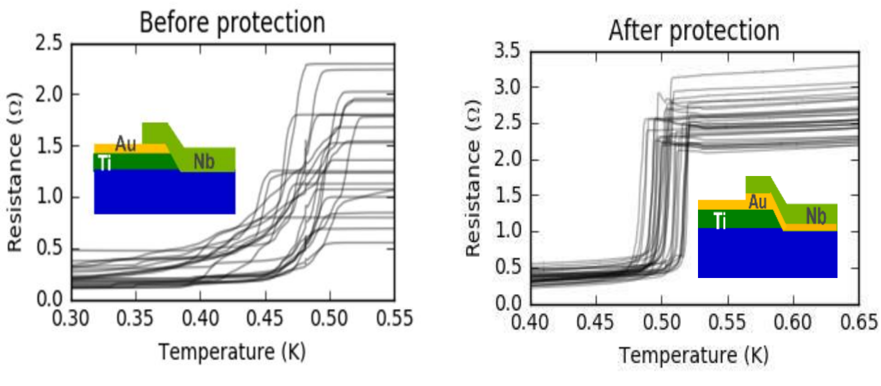

Fig. 4 SC transitions of TESs from wafers without *(left)* and with *(right)* a 30 nm Au additional diffusion barrier layer between the TES edges and Nb leads**.** Inserts show cross section of TES-Nb leads connection.

As an example, it was reported in [11,12] that interaction between titanium (in Ti/Au or Ti/Pd/Au contact pads) and Nb layers leads to significant variation of the critical current density in Josephson junctions in SC integrated circuits. The effect was attributed to hydrogen contamination of Nb during wafer processing, and migration of impurities along Nb wires towards Ti because Ti is a stronger getter of hydrogen. The influence of hydrogen impurities on Ti and Nb properties is well known [13,14]. Hydrogen contamination may be responsible for the observed variation of TES surface morphology and SC properties, but this needs to be verified.

We investigated the use of Mo, Pd, and Au barriers between the TES and Nb leads to prevent diffusion of impurities through the contacts. TES edges were covered with different passivation layers and tested after Nb contacts deposition. Surface modification of the area near Nb contacts indicated interaction between layers. We found that Mo (>30nm) or Au (>30nm) layers eliminated morphological defects but Au film enabled to exclude residual resistance and provided better reliability of electrical contacts. We compared Tc variation of TESs from wafers with and without additional Au (30nm) layer between TES-leads contact. As shown in Fig. 4, diffusion barrier decreased Tc scattering at least in two times and improved the SC transition shape significantly**.** Based on this result, we modified the contacts in the SPT-3G detectors to include a 30nm Au diffusion barrier.

3 Summary

We found morphological defects on the surface of Ti TESs, correlated with variations in the shape of the SC transitions. The effects are due to diffusion processes where Nb wiring contacts the Ti. We demonstrated that the reproducibility and sharpness of the SC transitions can be improved by adding a barrier to prevent diffusion of impurities in the contact areas. Monitoring of the surface morphology of Ti TESs can serve as a useful, non-destructive method of checking for contamination of the TES films.

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