Comparative Performance of Mo/Cu *vs*. Mo/Au Transition Edge Sensors for Space Science Applications

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Abstract—**The performance of Transition Edge Sensors (TES) based on Mo/Cu and Mo/Au is assessed. We have fabricated a number of TES bolometers from Mo/Cu and Mo/Au allowing TESs to be fabricated on free-standing micromachined membranes. The low stress conditions allow very thin SiN_x to be used for the membranes, which helps with achieving low-conductance thermal links and low heat capacity. Long-term stability against inter-diffusion is an intrinsic feature of Mo/Cu, but suitable passivation is needed to achieve long-term stability against corrosion. The Mo/Au bilayer does not need a passivation, Mo/Au TESs also show improved chemical, electrochemical and thermal stability compared to other bilayer combinations. The transition temperature of both Mo/Cu and Mo/Au is reproducible, sharp and tuneable over the whole range of temperatures need for space applications. The bolometer can be produced using standard lithographic techniques without any degradation of performance.**

INTRODUCTION

The rapid development of TESs over the last decade has led to their widespread use on ground-based and balloon-born mm-wave and submm-wave telescopes. Experience with TES technology in these instruments has increased its technology readiness level, and has paved the way for use on future space missions such as B-POL, SPICA and FIRI [1-3].The next generation of space missions covering the mm-wave to far-infrared bands will require large-format arrays of extremely low-noise detectors and the sensitivity should increase by at least two orders of magnitude. The current TES detectors developed for ground-based applications have NEPs of around 10^{-17} $WHz^{-1/2}$ [4-8]. In space applications, where the background loading is considerably lower than the best terrestrial sites the required NEP drops to on order 10^{-19} $WHz^{-1/2}$.While it is technically feasible to manufacture single TESs having this sensitivity, it is challenging to create an ultra-low-noise TES technology that can be engineered into complete imaging arrays, with the needed optical packing and uniformity of performance.

DETECTOR FABRICATION

Our TESs consist of superconducting Mo/Cu or Mo/Au bilayers that sit on a silicon nitride membrane isolated from a heat bath by thin legs with different widths and lengths. We are using Nb as a bias connection (Fig. 1, 2).

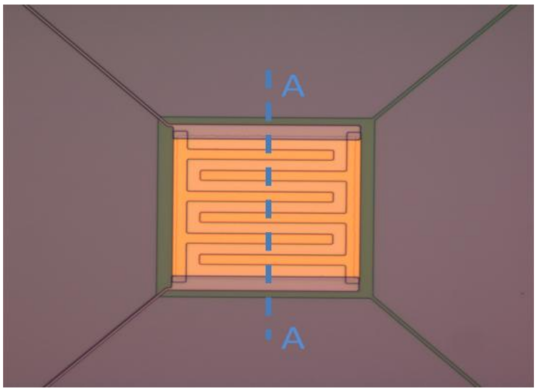

Fig. 1. A single Mo/Au TES with thick Au banks and fingers partially across the TES. The SiN_x island is 200nm thick. The dashed line A-A refers to Fig. 3

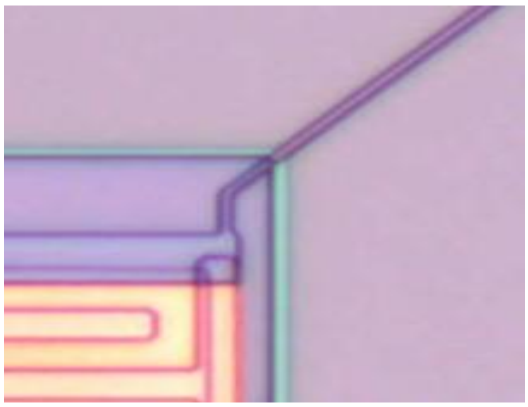

Fig. 2. Mo/Cu TES with 1µm SiN_x (200nm thick) legs, 1µm Nb connection and SiO_2 passivation layer.

The devices are fabricated on 50mm, 225 µm thick <100>, double-side polished Si wafers. These wafers have a 50 nm thermal oxide and 200 nm of low-stress SiN_x, formed by low-pressure chemical vapour deposition, on both sides. Ultimately the silicon nitride becomes a suspended membrane, produced by back-side etching of the supporting silicon substrate, to give the required thermal isolation.

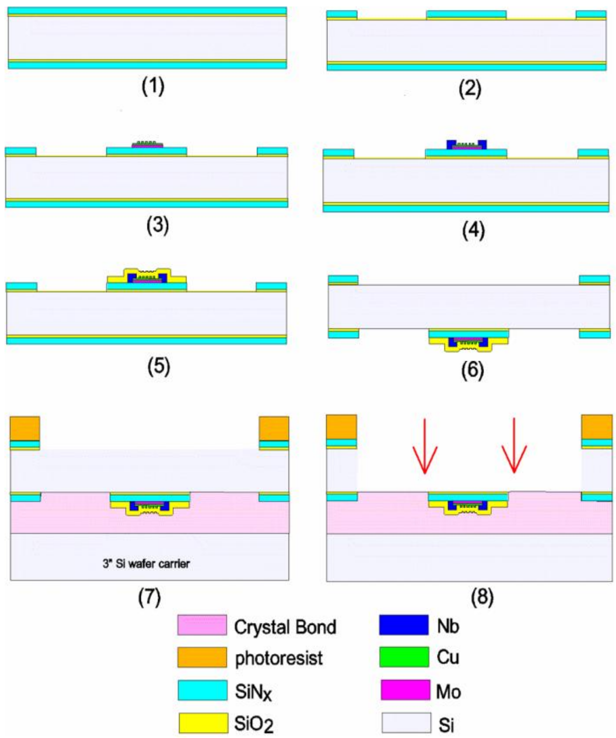

Fig. 3. Schematic process flow for device fabrication. Cross-section along the dashed line shown Fig. 1.

Device fabrication starts with a Reactive Ion Etch (RIE) of the SiN_x using CHF_3 gas to outline the devices and define the membrane and legs (Fig. 3.2). The bilayer is deposited by dc magnetron sputtering with a base pressure of ~ 1 x 10^{-9} Torr, and consists of a Mo layer followed by a Cu or Au layer deposited in quick succession to prevent any oxidation of the interface. The bilayer is then patterned by wet etching the Cu in a 5% solution of ammonium persulfate and water. The gold is etched in commercial Gold Etchant (iodine plus potassium iodide). Then the Mo is etched in commercially prepared aluminium etch. Additional normal metal Cu or Au banks and zebra stripes [9] are added by sputtering through a photoresist lift-off stencil covering the edges of the bilayer (Fig. 3.3) [10]. The bias connection of Nb, is then deposited and patterned by lift-off (Fig.3.4). The SiO_2 is used as a passivation layer for Cu. The SiO_2 layer is removed from unwanted areas by lift-off (Fig3.5). The device is then ready for the RIE silicon nitride etching on the back of the wafer and bonding face down to a carrier wafer (Fig. 3.6 and Fig. 3.7). The last step is the fabrication of the suspended membrane, which requires removal of the supporting Si from the window using Deep Reactive Ion Etching, thus leaving the TES membrane suspended on nitride legs.

RESULTS AND CONCLUSIONS

We have developed deposition and processing techniques for Mo/Cu and Mo/Au TES detectors. The same geometry was used to fabricate Mo/Cu and Mo/Au TESs (Fig. 4).

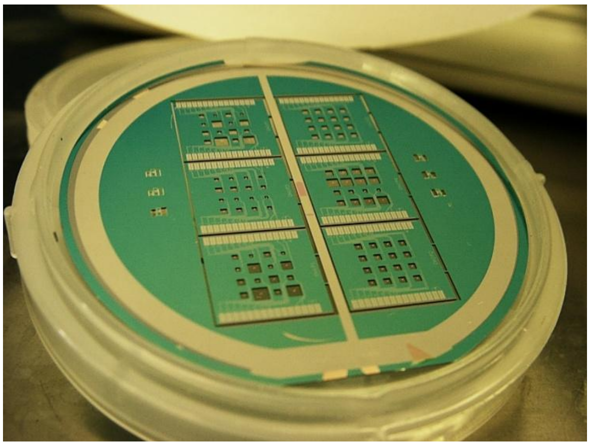

Fig. 4. Completed wafer

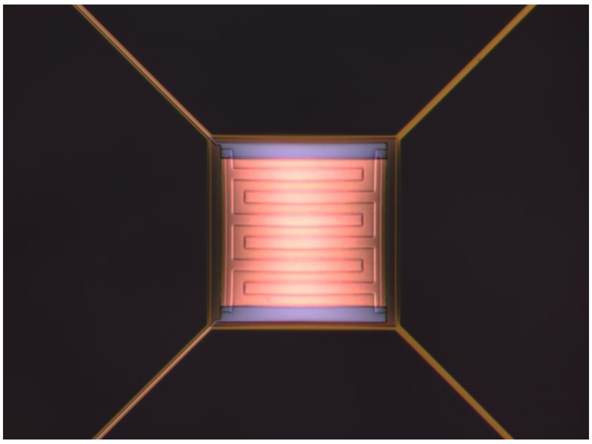

Fig. 5. A single Mo/Cu TES on 200nm SiNx membrane suspended on 4.2µm width and 420µm length legs.

We measured the superconducting-resistive transition of 40nm Mo/30nm Cu and 40nm Mo/30nm Au. In both cases the transition is reproducible and sharp. Fig. 6 and Fig. 7 show a typical resistive transition for the process devices.

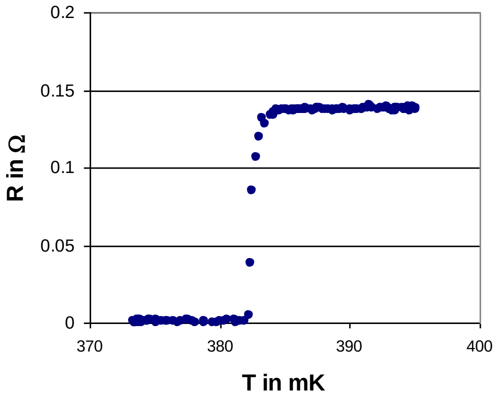

Fig. 6. Typical resistive transition of Mo/Cu (40/30nm) TES

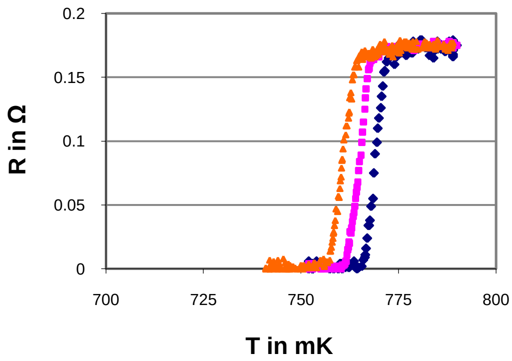

Fig. 7. Resistive transition of a Mo/Au (40/30nm) TES

We fabricated devices with different Mo/Cu bilayer layup, 40nm/30nm, 40nm/81nm and 40nm/106nm. The transition temperature is 382mK, 210mK and 122mK respectively. Typical Tc for Mo/Au (40nm/30nm) is 765mK. For different thicknesses of Cu and Au layers we measured the electrical conductivity (Fig. 8) which is related to the thermal conductivity through the Wildemann-Franz law. High thermal conductivity reduces noise due to internal thermal fluctuations [11].

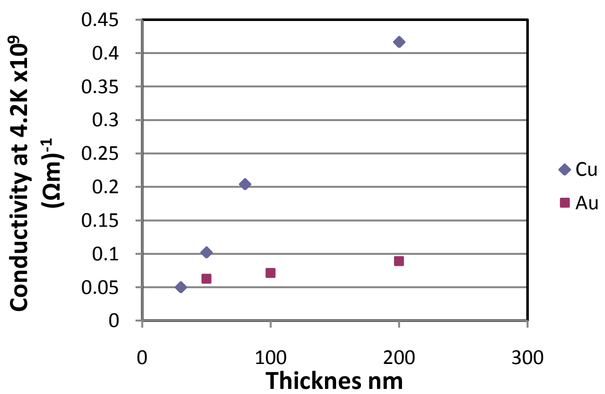

Fig. 8. Conductivity for different thicknesses of Cu and Au layers.

Mo/Cu and Mo/Au TESs are an establish technology and suitable for space application. Low stress Mo/Cu and Mo/Au bilayer films allow TESs to be manufacture on free-standing micromachined membranes. Long term stability against inter-diffusion is an intrinsic feature of Mo/Cu and Mo/Au bilayer [12]. Mo/Au shows long term-stability against corrosion. For Mo/Cu to achieve this stability it needs suitable passivation, in our case SiO2, although can be difficult to get good adhesion to Cu. The transition of Mo/Cu and Mo/Au is reproducible, sharp and tunable over the whole range of temperatures needed for space applications. The bolometers can be produced using standard lithographic techniques without any degradation of detector performance. Mo/Au TESs are extremely rugged devices and they can withstand extraordinary – including prelaunch – environments. This is a consideration specific to space application.

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