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The Study of Properties of Mo-Cu Bilayer Films for Space Science Applications

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* This is my PhD thesis work

Introduction

Hot Universe Baryon Surveyor (HUBS)[1] will focus on the major scientific issue of "missing" baryons. Since the expected radiation is in the soft X-ray band (<~1 keV) and is very weak, HUBS will use an X-ray microcalorimeter based on transition-edge sensors (TES) and an adiabatic demagnetization refrigerator (ADR) is employed to reach the detector working temperature (<100 mK). **Mo-Cu bilayer films** are selected as the basic material of TESs by using proximity effect. When the TESs mounted in HUBS runs in space, it may be affected by the space radiation environment, so that the performance of the TESs is deteriorated. In this poster, a series of work was carried out on Mo-Cu bilayer films -- preparation and measurements of Mo-Cu bilayer films, irradiation experiments with MeV protons and annealing experiments.

Preparation and Measurements of Mo-Cu Bilayer Films

- The Mo-Cu bilayer films were deposited by **DC magnetron sputtering** with a base vacuum pressure better than 5×10^{-8} Torr at room temperature, as shown in **Fig. 1**.
- The structure of Mo-Cu film is shown in **Fig. 2**.
- The Mo-Cu bilayer films were patterned and chemically etched to produce rectangular, as shown in **Fig. 3**.
- A commercial adiabatic demagnetization refrigerator (ADR) was used to measure the superconducting transition temperature (T_c), electrical resistance and residual resistance ratio (RRR) of each bilayer, as shown in **Fig. 4**. **T_c < 100 mK; RRR ~ 3**.

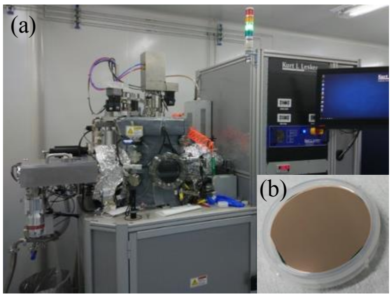

Fig. 1 (a) DC magnetron sputtering; (b) Mo-Cu film sample.

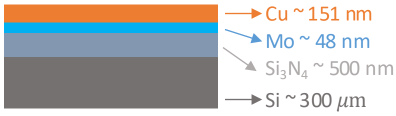

Fig. 2 Structure of Mo-Cu bilayer film.

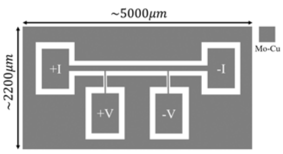

Fig. 3 Layout of Mo-Cu bilayer test samples.

Fig. 4 ADR measurement setup.

Irradiation Experiments with 1 MeV Protons

Experiment Setup

- The proton irradiation experiment was carried out at the 4.5MV Van de Graaff accelerator[3].
- To carry out low-temperature measurements, a liquid nitrogen dewar was installed at the facility, and integrated with a sample stage. The whole irradiation system is shown in **Fig. 5**.
- Two groups of measurements were made under **room** and **liquid nitrogen** temperatures, respectively, but at the same irradiation fluence of about $10^{15}\ ions \cdot cm^{-2}$. Each group of measurements involved four film samples and two PT100 thermometers, with one film sample and one thermometer shielded from the irradiating beam, as shown in **Fig. 6**.

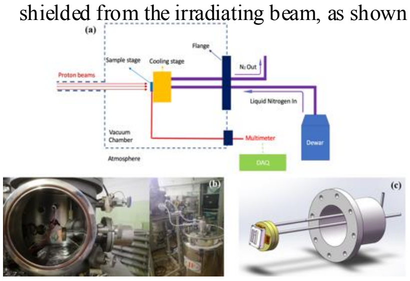

Fig. 5 Proton irradiation system: (a) schematic diagram; (b) vacuum chamber photo; (c) CAD drawing.

Fig. 6 Mounted film samples and thermometers: (left) without lid and (right) with lid.

Experiment Results

- The temperature of thermometers and resistance of Mo-Cu film samples were measured during the radiation process, as shown in **Fig. 7**.
- The T_c and 3K electrical resistance (ρ_{3K}) were measured of all film samples in the same ADR runs, before and after irradiation, respectively, as shown in **Fig. 8**. The irradiated films are indicated by circle, star and triangle symbols, and the shielded films by square symbols.

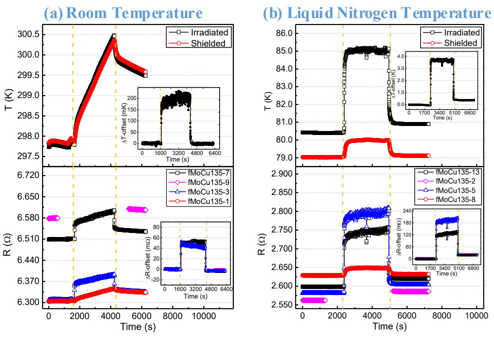

Fig. 7 Time series of thermometer reading (top panels) and sample resistance (bottom panels, with the shielded sample in red).

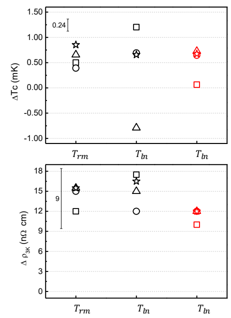

Fig. 8 The change in the T_c and ρ_{3K} values of the film samples before and after irradiation.

Annealing Experiments

Experiment Setup

- The annealing experiments were carried out at the E-beam system, as shown in **Fig. 9**.

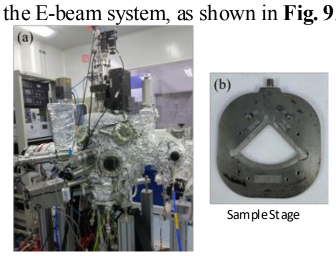

Fig. 9 E-beam system.

Experiment Results

- Different annealing temperatures, same annealing time (20 min), at vacuum environment.
- Tc of film samples is ~280 mK.

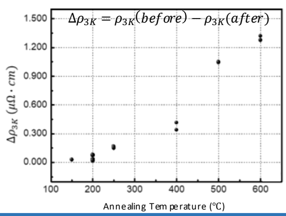

Fig. 10 The change of 3K resistivity (ρ_{3K}) of film samples after annealing.

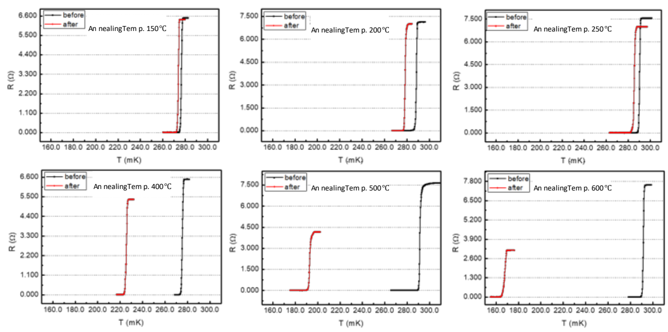

Fig. 11 R-T curve before and after annealing.

Conclusions

- After long-time and hard work, well-qualified Mo-Cu bilayer films can be produced.
- Proton irradiation did have influence on films, such as increasing the resistance of films which can be only confirmed under low temperatures. The influence on Tc is not confirmed yet.
- Annealing could decrease Tc and 3K resistivity of bilayer films. This effect would be stronger at higher annealing temperatures without changing the superconductive properties of films.

References [1] W. Cui, J. Bregman, M. Bruijn, L.B. Chen, et al. "HUBS: a dedicated hot circumgalactic medium explorer," Proc. SPIE 11444, Space Telescopes and Instrumentation 2020: Ultraviolet to Gamma Ray, 114449C (2020).