Simplified patterning of Mo/Cu transition edge sensors
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Abstract
Superconducting/novel metal layer bilayers with tunable Tc are widely used as transition edge sensors in high-resolution microcalorimeters. When these layers are patterned, channels with enhanced Tc (compared to the bilayer film alone) along the edges of the device where the superconductor is only partially covered by normal metal. Superconductivity near the edges can be suppressed by deposition of additional normal metal to cover the exposed superconducting edges. Alternatively, the same effect can be obtained by producing an overhang in the normal metal of the bilayer by using an isotropic etch to undercut the superconductor. For Mo/Cu bilayers, however, producing a reliable undercut with a wet etch proved difficult due to electrochemical corrosion of copper in the presence of molybdenum. We are trying out all-dry etch processes to achieve the desired geometry. This achieves the desired results, but we are still working on complete characterization of the etch. This is also part of an effort to reduce longitudinal proximity and weak link effects by minimizing the amount of material with much higher or lower Tc in contact with the bilayer, which should simplify the transition behavior and improve reproducibility. We are experimenting with devices that have normal metal zebra stripes and use a minimum volume of molybdenum (Tc = 13 K) rather than niobium (Tc = ~9 K) for the contacts.

1. Introduction

• A careful comparison of the metals produced by stars and supernovae 2 billion years after the Big Bang and current observations shows us that we see only 20% of the total metals produced. (The missing metals problem).

• Majority of these thought to reside in the Circum-galactic medium (CGM) and the Warm-Hot Interstellar Medium (WHIM). Their high metallicity environments make X-ray observations one of the best ways to study them.

• Astrophysical plasmas at temperatures close to 1 keV are ubiquitous. Substantial parts of the Galactic halo and disk appear to be at this temperature, including most of the volume within 100 pc of the Sun (The Local Hot Bubble).

• Bulk of the emission from these plasmas are at 600 eV or lower. To better understand the physics of the ISM, we need to be able to resolve the individual lines from such a plasma (and there are a lot of them).

The above figure shows a simulation of a model spectra with 1, 2 and 8 eV FWHM detectors. 1 eV detectors are essential to be able to clearly resolve the individual lines at lower energy. That is our goal.

2. Design Specifications

The energy resolution of a microcalorimeter is proportional to (R(T)C(T))/T2, where R is the modification to the Johnson noise term defined as R = 1+z/1+z=1, M being an “excess” noise term of unknown origin, determined empirically. Here, a = 50/18/60/120 and βa = 50/18/60/120 are the usual definitions of logarithmic current and temperature dependence of TES resistance respectively. This implies we should minimize the total heat capacity C and operating temperature T and maximize thermometer sensitivity.

Getting a small heat capacity will be limited by the large X-ray absorber required. To achieve a total effective area of >2 cm2 with 256 pixels, we need X-ray absorbers about 1 mm2 size with good stopping efficiency over our primary energy range. A 500 eV X-ray will raise the temperature of our 1 pJ absorber by 80 μK. Assuming a = 400 at 10% R, the transition has a width of 1800 μK, and the excision is <4% of the transition. (Always linear!)

• J2 scales with the effective device width with a slope ~0.25 μK/μm (Morgan 2017). Using two-fluid model of TESs, and for device effective width of 32 μm, we expect α ~ 470 μK/μm.

Green line in plot indicates where TES devices made with this fabrication process land on the contour.

3. TES Fabrication

Bilayer Fabrication
We have developed an alternative deposition approach using low energy ion beam assisted deposition (IBAD) that does not require heating of the substrate and results in controllable stress as well as a clean superconductor/novel metal interface (Morgan et al., 2015, Jaeckel et al. 2016).

• Ion beam energy and flux give additional knobs to tweak and good control over film density and stress.

• Commonly encountered challenges in the fabrication of arrays include variations in Tc and other details of the transition surface from run-to-run and between neighboring devices.

• Evidence suggests that to some extent these issues from process variation, e.g. misalignment between different lithography steps of TES fabrication (Wakelam et al. 2018).

The usual process requires at least two lithography steps to pattern the bilayer, and a third to produce the banks to keep the device from shorting out along the edges. A final device is illustrated on the left.

We propose to further develop an alternative “self-aligned” process that defines all the important lateral boundaries of the TES from a single mask. The process is illustrated on the schematic on the right.

1. An argon ion-mill step first produces trenches through the Cu along the sides of TES.
2. It is followed by a pulsed XeF2 gas phase etch that etches the Mo and produces a controllable undercut of the Mo so that edges remain faceted and do not short out the device.
3. Subsequent wet etch steps remove the bulk of the unwanted Mo and Cu material between the devices, but do not come into contact with the critical sidewalls of the TES. This avoids any electrochemical corrosion issues which we encountered with wet-etching of Mo (Nelms et al. 2005).
4. We expect much improved repeatability as a result.

4. Absorber Fabrication

Gold, and why?
Gold has excellent thermalization properties for rapidly turning the X-ray photon energy to heat, a very high thermal diffusivity which will be important for the large absorbers. The Gotted group has a well-developed process for making gold-based “nushroom” absorbers. So despite its high specific heat, our baseline design calls for all gold absorbers.

Opening patterns are in a first photolithography step (PR I) for the absorber stems. This first layer is then hard-baked to produce rounded sidewalls and render it stable against further exposure. PR layer it is then spun and patterned with the intended corrugation pattern (with the stem area once again opened to the TES). Another heat treatment reflows the photoresist to have the desired angled sidewalls. Gold is evaporated onto this “mold” to obtain good sidewall coverage, the substrate can be held at an angle on a rotating platform.

Figure above shows that a 200 nm layer of gold is still 99% efficient at stopping Krays up to 500 eV (Henze, 1993).

Cut-away view of the proposed gold absorber structure (not to scale). Corruptions provide bidirectional softening.

In the final step, the photore sist are dissolved away and we are left with free-standing orthogonally corrugated gold absorbers attached to the TES via stems.

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References