
Study of Dissipative Losses in AC-Biased Mo/Au Bilayer Transition-Edge Sensors

We are developing a kilo-pixel array of transition-edge sensor (TES) microcalorimeters for the X-Ray Integral Field Unit of the future European X-Ray Observatory Athena. Recent measurements of AC-biased Mo/Au bilayer TESs imply a dissipative loss at the TES. These measurements are made using a resonant circuit in the frequency range of 1-5 MHz. In this paper, we present the results of our measurements and discuss the cause of the AC losses. The AC bias currents used in these measurements are so low that under DC-bias, with the same nominal Joule power heating, the TESs would remain in the superconducting state. However under AC bias there is loss at MHz frequencies, which is frequency dependent and can be non-negligible even when biasing within the TES transition. The dissipation behaves as a series resistance within the TES, and therefore alters the transition shape, lowering the steepness of the transition, particularly low in the transition. This will affect the key properties that determine the microcalorimeter energy resolution. We measured AC losses and transition properties on various TES geometries.

We modeled the TES using a finite element method (FEM) and simulated the AC loss. The loss measurements on various TES devices and the FEM simulation results indicate a causal relationship between the loss and the normal metal area exposed to the self-induced magnetic field, implying that the loss is due to Eddy current heating.

1. Introduction

✓ developing a TES array for Athena
✓ optimizing the design to use under AC bias using SRON FDM warm electronics (Ravera+ 2014)

2. TES Types and Geometries

We measured dissipative losses for...
✓ 4 TES sizes: 50, 100, 120, and 140 um
✓ 2 wafers with different sheet resistances: regular and high TES impedance
✓ 5 different geometries: stripeless, 1 stripe, 3 stripe, T stem, and 5 stripes

3. Measured Dissipative Losses

Resonance lines are fitted and dissipative losses are calculated as equivalent series resistances (ESR)
✓ Larger losses for higher frequencies
✓ Larger losses for TESs with larger volume of normal metals (e.g. larger TES size / more stripes)

Imples losses are due to Eddy currents!

4. Impact of Losses toward R-T and alpha

Loss behaves as a series resistance and broadens transitions
Loss also makes α frequency dependent
No significant transition broadening for TESs without absorbers
Goal: ESR@5MHz < 2% of R₀

5. FEM Simulation on Dissipative Losses

We modeled our TES with FEM (COMSOL) and simulated dissipative losses

Frequency dependence was reproduced
Losses are mainly attributed to EM fields induced in wires

6. Mitigation to Dissipative Losses

Simulation shows...
✓ taller absorber heights make losses smaller
✓ smaller “loop” sizes make losses smaller
✓ keeping wires as microstrips closer to TES as much as possible minimizes losses

7. Summary & Conclusion

✓ Dissipative losses were measured for different TES sizes, different TES impedances, and different TES geometries
✓ TESs with larger volume of normal metals show larger dissipative losses implying dissipative losses are due to Eddy currents
✓ Dissipative losses broaden TES transitions and degrade α and energy resolution
✓ To minimize losses - microstrip as close to the TES as possible and increase absorber height

References

Ravera et al. 2014, SPIE Proc., 9144, 914457


M. Kiviranta (VTT)

SEM Image

32±12 GSFC Mo/Au TES w/ Bi/Au Absorbers (Smith+ 2016)

ESR @ TES Side (⊿)

50 um Stripes

1 Stripe

3 Stripes

T Stem

5 Stripes

TES (GSFC)

Dot stem (normal)

TES (GSFC)

Absorber (normal)

Tes (normal)

Leads (super)

TES Modeling and Dissipative Loss Simulation with FEM

Absorber Height vs Equivalent Series Resistance for 50 um Stripes TES

Absorber Height vs Equivalent Series Resistance for 33 um Stripes TES

Wire geometry to minimize losses

Absorber Height vs Equivalent Series Resistance for 30 um Stripes TES

Absorber Height vs Equivalent Series Resistance for 50 um Stripes TES

Volumetric Loss Density at Absorber (W/m3)

TES: 50 um

50/100/120/140 um

Higher losses for high impedance TESs are possible due to lower resistance at absorber

Higher losses for high impedance TESs are attributed to EM fields induced in wires

Kazuhiko.Sakai@nasa.gov

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-losses due to Eddy currents