

## Microcalorimeter Detectors for Next-Generation X-ray Spectrometers

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As advances in semiconductor manufacturing continue to push the minimum feature size of devices to smaller and smaller dimensions - now only a few hundred nanometers - the semiconductor industry is facing a critical need for next-generation analytical tools for the inspection, characterization, and compositional analysis of contaminant particles and defects as well as for the analysis of nanometer-scale device structures. In order to perform compositional analysis on nanometer-scale features, the X-ray generation volume in the sample must be nanometer length scale as well. Using modern field emission scanning electron microscopes, it is possible to reduce the X-ray generation volume to a depth under 100 nanometers for high spatial resolution imaging by operating at reduced electron beam energies. At these low energies, however, the electron beam excites only low-energy elemental X-ray lines, which conventional semiconductor detectors are unable to resolve owing to peak overlaps at these low energies. Cryogenic microcalorimeter X-ray detectors based on superconducting transition edge (TES) sensors offer a roughly 50-fold improvement in energy resolution as compared with conventional semiconductor detectors for energy-dispersive spectrometry (EDS). The best energy resolutions demonstrated to date are 2.0 eV full width at half maximum (FWHM) at 1.5 keV [1] and 2.4 eV FWHM at 5.9 keV [2]. The energy resolution of state-of-the-art microcalorimeter detectors rivals the resolution of spectrometers for wavelength-dispersive spectrometry (WDS), yet microcalorimeters offer all the advantages of EDS detectors - ease of use, long-term stability, and the ability to quickly provide qualitative as well as quantitative chemical analysis. An X-ray microcalorimeter consists of three parts: an absorber that captures the energy of the incident X-ray, an extremely sensitive thermometric element to measure the temperature rise of the absorber following an X-ray absorption event, and a support and thermal isolation structure that determines the rate of heat loss from the microcalorimeter. The thermometric element for a TES microcalorimeter consists of a superconducting thin film operated at its superconducting transition. A TES is particularly attractive as a thermometric element owing to its high sensitivity  $\alpha = d(\log R)/d(\log T)$  and fast response time achievable using a novel electrothermal feedback [3] technique. Normal metal/superconductor bilayers are typically used to fabricate transition edge sensors, since the superconducting critical temperature can easily be tuned to the desired operating temperature (around 0.1 K) by adjusting the strength of the proximity-effect coupling, and they can be made with low resistivity to ensure fast thermal response times. Following a photoabsorption event, the sudden temperature rise of the microcalorimeter results in a current pulse through the TES (the height of the pulse being proportional to the incident X-ray energy), which is measured using a low input-impedance superconducting quantum interference device (SQUID) amplifier. The third part of a TES microcalorimeter is the thermal isolation structure, usually a thin membrane upon which the TES bilayer and absorber are fabricated. Typical TES microcalorimeters are fabricated on a micromachined silicon nitride membrane formed by depositing a low-stress, silicon-rich silicon nitride film on a Si wafer and then etching the backside of the wafer [4] down to the membrane, or using a surface micromachining technique to preferentially etch away a sacrificial layer underneath the silicon nitride membrane [5]. More recently, we have developed a polymer membrane process for the fabrication of surface micromachined Mo/Cu TES microcalorimeters and multi-pixel arrays. These detectors are being

used to develop a compact, next-generation EDS spectrometer based on a cryogen-free adiabatic demagnetization refrigerator (ADR).

References

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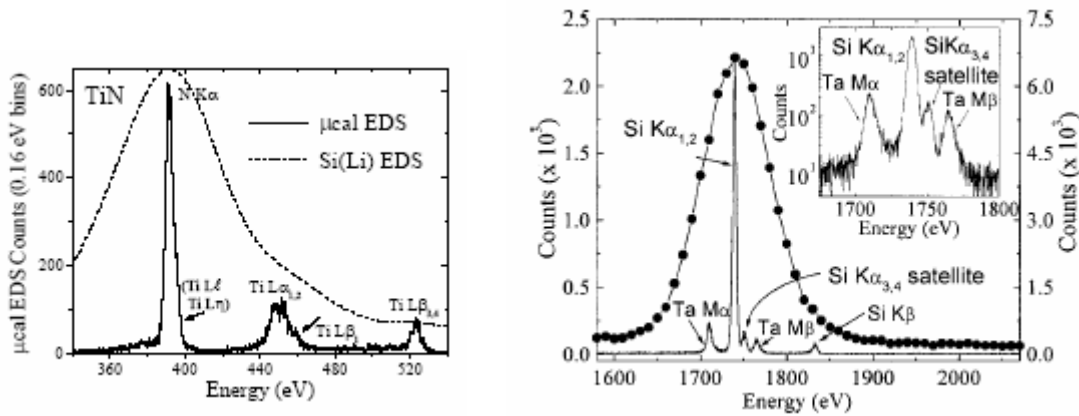


Figure 1. Comparison of microcalorimeter and semiconductor EDS spectra for TiN [1] (left) and for a TaSiN film on Si [7] (right).

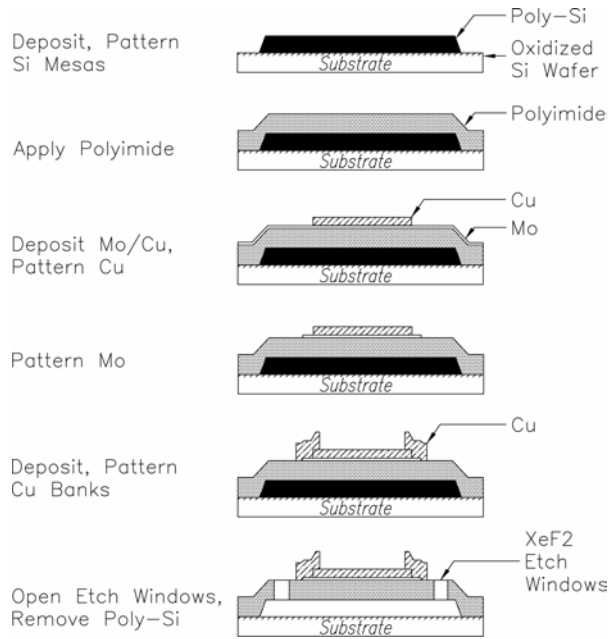


Figure 2. Cross-sectional view of a surface micromachined TES microcalorimeter. A Nb wiring layer deposited prior to removing the sacrificial poly-Si is not shown.