Improved Energy Stability in the NIST Microcalorimeter X-Ray Detector

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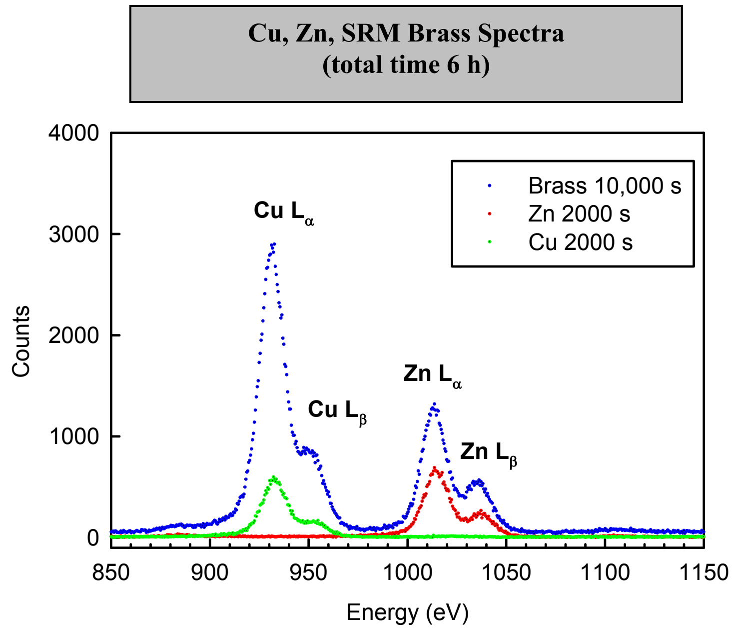
The CSTL research team investigated the sources of energy scale drift in the NIST-developed microcalorimeter x-ray detectors and has addressed the most critical elements.

Microcalorimeter x-ray detectors make up a new technology that combines some of the positive features of wavelength dispersive (high resolution) and energy dispersive (parallel detection over a wide energy range) detectors that have gained broad acceptance in the microanalysis community. Microcalorimeters which use a transition edge sensor (TES) have proven to be effective over energy ranges of 10 keV or more in applications such as x-ray fluorescence analysis with electron microscopes. TES microcalorimeter x-ray detectors have successfully demonstrated energy resolutions better than 5 eV. However, serious drifts in energy scale over extended counting times have set limits on both the long-term resolution and the calibration of these detectors. This is because the operating point of the detectors is the middle of the superconducting-normal phase transition. The successful operation of a microcalorimeter as an x-ray detector puts considerable constraints on the stability of all the electrical and thermal inputs to the instrument. Previously observed drifts of >10 eV/h have been reduced to 1 eV/h to 2 eV/h. This improved stability, shown in the figure, has resulted in the observation of x-ray fluorescence linewidths of 12 eV to 15 eV over a 6 h time period.



The detector is cooled to a substrate temperature of only 70 mK and maintained at its operating point by a complex feedback control system connected to a large superconducting magnet. We carried out a careful analysis of the performance of all the elements in the control system including the response function of the magnet under typical conditions of operation. We determined that the desired stability and performance of the detector required control of its substrate temperature to a precision of 23 μK, that is, a variation of less than 5 parts in 10,000. By careful modification of the control circuitry, we have been able to realize this degree of temperature stability of the substrate. The energy scale of the spectra is now observed to be stable to within about ≤1 eV/h over a period of hours, under operating conditions in which a linewidth of 12 eV to 15 eV is readily obtained. X-ray spectra acquired over long durations under these conditions of substrate temperature stabilization show vastly improved stability and resolution.

Additional measures to stabilize the operating temperature are possible. Once realized, we can carry out a demonstration of the microcalorimeter detector with an electron microscope for quantitative microanalysis. We also anticipate replacing the actual detector element with higher resolution (< 4 eV) versions, which have been developed at NIST, Boulder. Combined with the achieved stability of the energy scale, we can start to look at characterizing chemical states of some elements by the energy of their fluorescence lines.

The drift in energy scale of the microcalorimeter x-ray detector has been a major limitation to the commercial development and marketing of this type of detector. There are currently a number of potential applications of this detector, particularly in the semiconductor industry.