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Aging of a Thermoelectric Module: Visualization of Elemental Analysis

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1. Background
The thermoelectric effect allows a thermal gradient to be converted into electricity. This thermoelectric module (TM) is an array of n-type Bi$_2$(Te,Se)$_3$ and p-type (Bi,Sb)$_2$Te$_3$ semiconducting pillars. Two ends (cold and hot) of the TM have Au bridges defining the circuit path.

After successful operation under thermal gradient and load for ~5 months, X-Ray Fluorescence (XRF) was used to non-destructively investigate all surfaces of the aged TM. XRF detects energies of x-rays fluoresced from a sample. The energies are used to identify and map individual elements. Relevant XRF energies and the spectrum corresponding to the elements are shown below.

2. Visualization
Single-element XRF maps are shown for six elements detected in the TM. Four surfaces mapped for Au and Bi compare the interior and exterior of two modules: an unaged and an aged module. Images and maps are cropped so that only a portion of the TM is shown. Each element is mapped on an intensity scale chosen to best visualize its spatial distribution.

Map scales: black = no signal, red = maximum signal

3. Results
Au is the only element that differs spatially after aging the TM.
- Diffusion of Au along the aged exterior is seen, but not in the interior of the TM.
- This effect is observed only from the hot end of the aged TM.
- On the n-type material, Au has reached all the way to the middle of the temperature gradient.
- The p-type material shows a steeper Au gradient.

No other element shows any effect of aging at this scale, nor do they show differences between the interior and exterior of the TM.
Sulfur appears to be a signature of the adhesive between the pillars.

4. Conclusion
The maps constructed from XRF data show the expected elemental distribution except in the case of Au, which on the exterior surface of the aged module has diffused from the Au-plating on the hot end towards the cold end. This phenomenon is confined to the exterior of the TM. Diffusion has progressed further along the surfaces of the n-type material than the p-type. Diffusion of Au along the surfaces of the TM may be driven by the operating conditions of the aging test. Location of Au suggests thermally driven diffusion.

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