Balancing on the Edge: Detecting X-rays with Transition Edge Sensors

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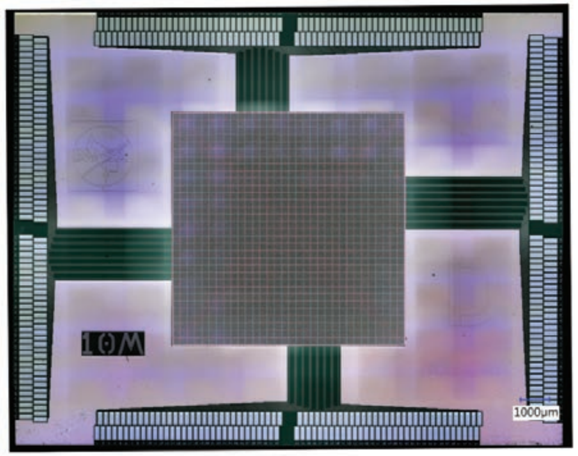
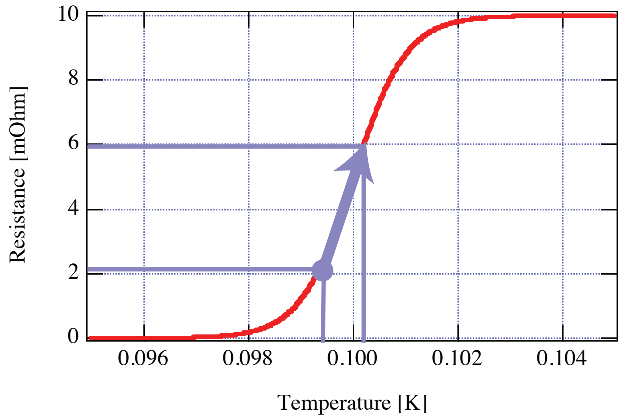
At the core of the X-ray Integral Field Unit (X-IFU) is a powerful array of X-ray detectors that will allow us to detect the energy of incoming X-rays with exquisite energy resolution. We require a FWHM (Full Width at Half Maximum) energy resolution of less than 2.5 eV for energies up to 7 keV. The basic detection principle couldn't be simpler. We use calorimeters in which the energy of an X-ray is converted into heat within a pixel, and the size of the ensuing temperature rise is used to determine the energy. But to successfully meet the desired level of sensitivity, we need to use a thermometer with extremely high sensitivity to temperature changes. A 7 keV photon will raise the temperature of each pixel by only ~1 millikelvin, meaning that the basic accuracy of temperature measurement needs be a fraction of a microkelvin!





Left: Photograph of a prototype array developed for the X-IFU demonstration unit. It consists of 1024 pixels on a 0.25 mm pitch. Each TES pixel is attached to an absorber consisting of 1.7 μm of Au and 3 μm of Bi. *Right*: Resistance vs temperature curve of a typical TES phase transition. Credit: *X-IFU* Team.

The temperature sensor technology we are using is called a Transition-Edge Sensor (TES). In this device, we bias a thin superconducting metal film (typically a bilayer of molybdenum and gold) in-between its superconducting and normal metal states, so that any tiny increase in temperature will produce a relatively large change in resistance. This type of detector has been demonstrated to be the most sensitive, as well as being the technology that is most easily read-out in a multiplexed way, which is essential for reducing the cryogenic requirements of the X-IFU and also to keep the mass and power of the electronics sufficiently small. However, while this type of sensor is the best available, it is based on phase transition properties that are extremely hard to calculate from fundamental physics. Indeed, many condensed matter theorists might think we would be crazy to work with a detector based upon working in such a complicated system. In addition to their complexity, TES phase transitions are notoriously sensitive to just about anything you could imagine, from the magnetic field environment to the design of leads that connect each TES to the SQUID (Superconducting Quantum Interference Device) read-out.

For the past decade, the X-IFU team has gradually managed to identify the most important physical processes that affect the TES performance. We have been learning what precisely determines the shape of the transition resistance versus temperature curve, or more accurately the resistance versus temperature, current, and magnetic field surface. In recent breakthroughs, we have managed to make devices that not only have the desired energy resolution, but also allow us to make transitions that appear to be sufficiently smooth, uniform and reproducible that we will be able to meet the X-IFU uniformity, yield, and calibration accuracy requirements. These new results are about to be published, so stay tuned for more on this evolving breaking story!