Title of Investigation:

Development of Kinetic Inductance X-ray Detectors for Large-format Arrays

Principal Investigator:

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Other In-house Members of the Team:

From Code 662: Dr. Fred Finkbeiner, Dr. Caroline Kilbourne, Dr. Richard Kelley, Dr. F. Scott Porter, Dr. Tarek Saab, Dr. Simon Bandler, and Regis Brekosky

Other External Collaborators:

Dr. Peter Day (Jet Propulsion Laboratory) and Dr. Jonas Zmuidzinas and Dr. Fiona Harrison (California Institute of Technology)

Initiation Year:

FY 2004

Aggregate Amount of Funding Authorized in FY 2003 and Earlier Years:

$0

FY 2004 Authorized Funding:

$50,000

Actual or Expected Expenditure of FY 2004 Funding: In-house fabrication:

$27,000; fabrication materials: $2,600

Status of Investigation at End of FY 2004:

Continue research with extension of 2004 funds into 2005.

Expected Completion Date:

September 2005

Purpose of Investigation:

The purpose of this investigation is to develop next-generation X-ray imaging spectrometers with high-energy resolution. The state-of-the-art in X-ray imaging spectrometers is the 6x6 array for the Astro-E2 mission. For Constellation-X, a 32x32 1-kilopixel array is under development. As is true for handheld digital cameras, the more pixels the camera has, the better the picture. Future X-ray astronomy missions will benefit from large-format (read "many-pixel") cameras because more pixels mean a bigger field of view. Larger pieces of the sky can be imaged in each frame, greatly lowering the number of pointings needed to cover a certain area of the sky. A larger field of view directly increases the amount and types of science that an orbiting X-ray observatory can do. The future of X-ray imaging spectrometers lies in mega-pixel instruments that will be used for such missions as Generation-X and MAXIM.

In this investigation, we are developing an exciting new device called a kinetic inductance detector. This detector uses superconducting mircrowave circuits and technology very similar to that found in cell phones to read out many (thousands) of pixels at one time. This results in a dramatic simplification of the detector array and associated cryogenic electronics, and harnesses the rapid advances in digital electronics for the wireless communications industry.

FY 2004 Accomplishments:

Before discussing what we have accomplished, first a little more background about the technology. Kinetic inductance is a physical property of superconductors that relates to how quickly moving electrons can change direction in the superconductor. In a kinetic inductance detector, an X-ray is absorbed into a superconductor, and its energy is transformed into "quasiparticles," which are high-energy electrons, and phonons, which can be thought of as units of heat in the material. These quasiparticles diffuse into the sensing element, which is a superconducting strip that forms part of a resonant circuit that oscillates at a particular frequency. The quasiparticles change the kinetic inductance of the superconducting strip, thus changing the frequency of oscillation of the resonator and its quality factor. By designing an array of detectors with different resonant frequencies, thousands of detectors could be read out through a single channel. Because these detectors are read out at microwave frequencies, they are referred to as Microwave Kinetic Inductance Detectors (MKIDs).

We are investigating the materials chosen for the MKIDs and absorber. The energy gap in superconductors is $2\Delta \approx 3.5k_BT_c$, where T_c is the superconducting transition temperature and k_B is Boltzman's constant. Lower T_c materials will create more quasiparticles for a given photon and thus will have a better statistical energy resolution. MKIDs at NASA's Jet Propulsion Laboratory (JPL) are currently made of aluminum (Al), and the absorbers of tantalum (Ta). For the absorbers, we are researching other materials, like tin (Sn), and for the MKID, our tunable T_c molybdenum/gold (Mo/Au) bilayers, which in principle could be made to maximize the energy resolution for a given design.

Tin as an absorber is, in a number of ways, similar to tantalum. It has slightly smaller energy gap and Debye temperature and it has comparable quasiparticle lifetimes. What makes tin attractive is its low-melting point, slightly lower than that of bismuth (Bi) which suggests that it would be a good candidate for making cantilevered absorbers using the same process that we use for Bi. We also have experience with observing X-ray thermalization processes in pure deposited Sn films below 100 mK. We have observed that half of the energy ends up in the quasiparticle system, with effective recombination times on millisecond time scales.

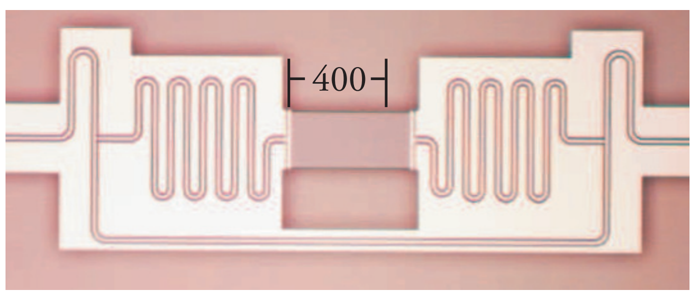


Fig. 1. Current JPL Kinetic Inductance Position-Sensitive Detector. The absorber is the tantalum rectangle labeled with the 400-um size marker. The resonators at each side are exposed to X-rays. For a viable detector design, the absorber must comprise a much larger fraction of the focal plane.

The group at JPL-Caltech are currently using tantalum absorbers on a two-MKID position-sensitive design. As can be seen in Figure 1, both MKIDs are exposed. Our goal is to fabricate large arrays with filling fractions of around 95% with a new design for enabling closed packed arrays of MKIDS with a bridge absorber. Figure 2 depicts the basic design. A long absorber lies 6 μm above the substrate plane, connected to the substrate at the two ends, as seen in the lower schematic.

Fig. 2. Kinetic Inductance Position-Sensitive Detector with a bridge absorber. The lower figure shows the front view of the absorber.

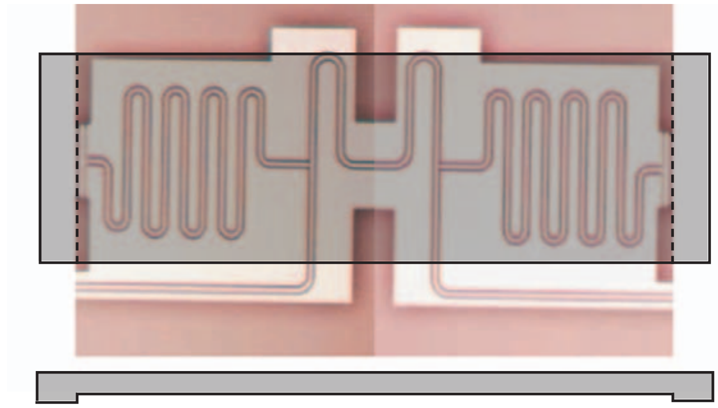
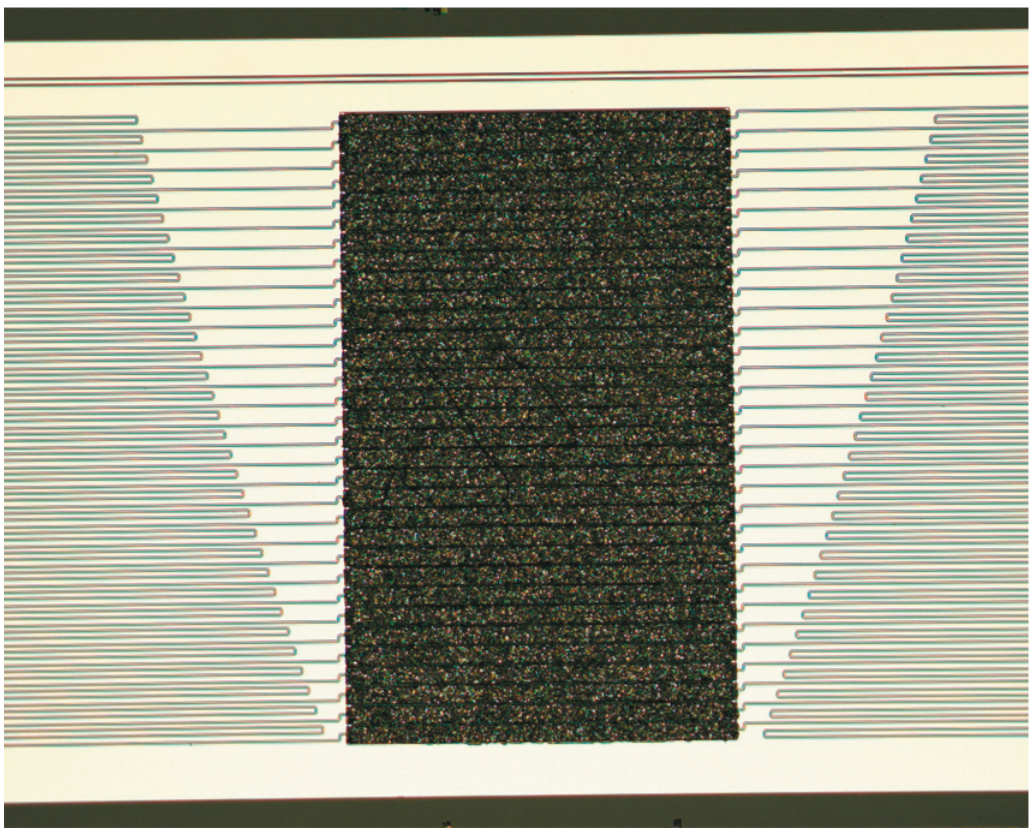


Figure 3. Picture of one of our detector arrays from our first wafer. The resonators are made out of aluminum, and the absorbers (the darker rougher metal) are made of tin. There are 32 position-sensitive MKIDs in this array, each operating at a different frequency.



Full characterization of both aluminum and tin films was done to ensure our understanding of the particular materials properties of these Goddard-deposited films and provide proper film resistances at cryogenic temperatures. We have successfully fabricated several devices using aluminum as the resonator material and tin as the absorber. Unfortunately, our first devices had an oxide between the resonator and the absorber, which prevented them from operating as intended. We are now moving to Mo/Au films as resonators as gold does not oxidize and should provide a clean interface for the tin.

Planned Future Work:

Mo/Au film resonators are being fabricated and will be tested at JPL by our collaborators in the coming months. We are also planning to fabricate bridge absorbers to use with these devices.

Summary:

This technology has the potential for mega-pixel, high-energy resolution imaging arrays due to their straightforward multiplexing capabilities. Using novel materials for the resonator circuits and the absorbers, as well as the absorber geometry, are all Goddard innovations to this research effort. Several future X-ray observatories will require wide field-of-view imaging spectrometers, with high-energy resolution. Goddard is a world leader in X-ray detectors, and developing this new kinetic inductance technology will help ensure that Goddard continues as a major player in the X-ray detector field. The main criterion for success would be testing a functioning MKID made at Goddard, preferably with a bridge absorber. Unforeseen difficulties in depositing and characterizing the aluminum and tin films, as well as a longer-than-expected time for procuring the required lithographic masks to fabricate the devices, delayed our progress in this effort. A thicker than expected oxide film in the aluminum resonators prevented us from testing our first devices. We are now fabricating a Mo/Au resonator that should solve this problem. Our proposal has been extended into 2005 and we expect to produce working devices in the coming year.