NORMAL METAL BOUNDARY CONDITIONS FOR MULTI-LAYER TES DETECTORS

This application claims benefit under 35 U.S.C. §119 of the provisional application, U.S. Ser. No. 60/157,741, filed Oct. 5, 1999.

Described herein are multilayer transition-edge sensors (TES) having improved performance, a method for preparing them and methods of using them. Specifically, the improvement lies in providing normal metal strips along the edges of the superconducting and normal metal layers parallel to the current flow in the TES during operation. These strips (hereinafter referred to as "banks") provide for both improved sensor performance and improved sensor robustness against corrosion. This improvement is an important advance particularly for the TES-based microcalorimeter detectors. The improved TES also have many other applications based on the very precise thermometer function achieved by the TES, as further discussed below. Such further applications are also contemplated by this invention.

BACKGROUND OF THE INVENTION

A wide variety of particle and energy detectors and other devices can be made using a superconducting TES as a thermometer; see, e.g., Wollman et al., *High-resolution, Energy-dispersive Microcalorimeter Spectrometer for X-ray Microanalysis, J. Microscopy* 188(3), pp. 196–223 (Dec. 3, 1997); and, Hilton et al., *Superconducting Transition-edge Microcalorimeters for X-ray Microanalysis, IEEE Transactions on Applied Superconductivity,* 9(2), pp. 3177–3181 (June 1999); both of which are incorporated by reference herein in their entirety. By operating the device such that the TES is held within its superconducting transition temperature region (i.e., the temperature region in which the material switches from normal conducting to superconducting property) any heat deposited in the TES can be very precisely measured due to the strong dependence of its conductivity (or conversely electrical resistance) on the temperature. Thus, very precise measurement and/or detection of a particle or energy source which provides even a minute heating effect can be performed. It is known that bilayers (and other multilayers) of superconductors with normal metals can provide excellent TES-based detectors; see, particularly Irwin et al. (U.S. Pat. No. 5,880,468) which is incorporated herein by reference in its entirety. For example, such multi-layers provide the ability to independently control the superconducting transition temperature (T_c) and the heat diffusion properties of the TES. However, without careful consideration of materials compatibility and fabrication techniques, multilayer TESs may have difficulties not observed in homogeneous TESs. These difficulties arise primarily in two areas, environmental or electrochemical degradation of the bilayer, and non-uniform conductivity at the edges of the TES.

The invention described here pertains to efforts made which overcame these difficulties.

SUMMARY OF THE INVENTION

For a TES to have low-noise operation it is important that the edges of the layer(s) parallel to the direction of current flow have uniform electrical conductivity. (The physical "edges" of the TES layers discussed here, also referred to as "outer sides" herein, should not be confused with the "transition edge" which pertains to the temperature "edge" between superconducting and normal properties). If some portion of the physical edges are superconducting and other portions are in the normal state, there will be non-uniform critical current along the length of the TES, causing phase-slip behavior and excess noise. Thus, the TES should be made as close as possible to either fully superconducting or fully normal boundary conditions.

While the increased critical currents obtained in detectors with fully superconducting boundary conditions offer somewhat improved performance over detectors with fully normal boundary conditions, bilayers (and thus multilayers) with superconducting boundary conditions are very difficult to achieve. Using Usadel theory, we calculated that if the superconducting layer of the TES is as little as 20 nm wider than the normal-metal layer, there will be a small region with a T_c higher than the bulk of the TES. It is also important that the interface between normal and superconducting layers be protected. Any corrosion of the interface along the film edges may decrease the proximity coupling of the layers leading to effects similar to those discussed above. Many of the material combinations suitable for use as multilayers suffer from strong electrochemical effects, which are likely to cause extensive edge corrosion. Problems such as these are often solved using an edge passivating film such as SiO_2 or Si_3N_4. However, for TES based x-ray and infrared detectors, this approach may be undesired because of energy loss due to energy trapping in the passivating film.

The most obvious method for fabricating a structure with normal-metal boundary conditions is to deposit a bilayer with normal metal on the bottom and patterning the two layers such that the upper superconducting layer is narrower than the base normal layer. We have fabricated such a structure using our preferred bilayer materials (Cu/Mo). A plot of the resistive transition versus temperature is shown by curve A of FIG. **1**. The transition is very broad with a "knee" indicative of two transition temperatures. It is believed that this poor transition can be attributed primarily to stress effects in the Mo superconducting layer, since refractory films such as Mo tend to be difficult to grow on softer films such as Cu. It is likely there is either stress cracking or delamination along the edge of the bilayer, leading to a variation in proximity-effect coupling across the width of the bilayer.

It is also possible to create a bilayer with normal-metal boundary conditions by depositing a bilayer with the superconductor on the bottom. The two layers are then etched, with the superconducting layer being over-etched so the top normal metal layer overhangs to obtain normal-metal boundary conditions. The resistive transition of such a structure is plotted in curve B of FIG. **1**. This transition, while greatly improved compared to curve A, also shows some undesirable structure. It is believed that this structure can be attributed to environmental effects such as corrosion at the bilayer edges.

According to the invention, therefore, a greatly improved superconducting transition can be achieved by adding normal metal "banks" covering the outer sides, i.e, "edges", of the multilayer TES parallel to the direction of current flow. If the structure of the layers is not square or rectangular the banks would cover the outer sides other than those through which the current flows, i.e., other than those which contain the leads. The banks are provided to cover the edges such that normal-metal boundary conditions are achieved. Such a structure is exemplified by FIG. **2**. There, an additional normal metal deposition and patterning is conducted to form the banks and provide both fully normal state boundary conditions and passivation of the bilayer sidewalls. By providing such banks, the preferably fully normal-metal boundary conditions are achieved and the disadvantages