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Observation of Bias-Specific Telegraph Noise in Large Transition-Edge Sensors

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***Abstract*—We have observed anomalous random telegraph noise in discrete regions of voltage bias throughout the superconducting transition in larger transition-edge sensors (TESs). The bimodal nature of these noise features is consistent with thermally activated switching across discrete jumps in the TES resistance. When a TES is biased near one of these regions, or the peak of the pulse response samples one of these regions, the energy resolution suffers. In this manuscript, we will present detailed measurements of these noise features in one of our TESs optimized for alpha-particle spectrometry.**

***Index Terms*—Superconducting transition, transition-edge sensors (TESs).**

MICROCALORIMETERS based on transition-edge sensors (TESs) have demonstrated the highest resolving powers of any energy-dispersive detector, as high as 4400 and 5000 for gamma-ray [1] and alpha-particle detectors [2] respectively. However, the energy resolution achieved in these detectors can change dramatically for small design changes. Also, within a single detector, a small change in the voltage bias point can strongly influence the measured noise. We have recently observed regions of anomalously high noise as a function of bias current in large TESs designed for alpha-particle spectroscopy. Preliminary details were reported elsewhere [3] where the noise was described as switching between two states, and appeared to be more prevalent in high-current-density devices. In this paper we show that the bias points and amplitudes of these noise features are reproducible and that the observed noise is consistent with thermally activated switching across a discrete jump in the resistance within the superconducting transition.

The details of the design and performance of these alpha-particle microcalorimeters are given in Refs. [3], [4]. These detectors are 1.2×1.2 mm^2 MoCu TESs with attached tin absorbers fabricated using the same process as our gamma-ray microcalorimeters [5]. The noise-mitigating normal metal features [6] are spaced 90 μm apart. Under typical operating conditions, the TES current at 50% R_n is 160 μA. The readout method was the standard voltage bias scheme, where the detector was biased by driving current through a shunt resistor in parallel with the detector, and the current through the detector is read out with a superconducting quantum interference device (SQUID) amplifier [7]. Data were acquired over the entire transition region by incrementally stepping the bias current, then taking a 0.25 second long record for each bias point. A 1 kHz low pass anti-aliasing filter was used to set the bandwidth of the measurement close to the L/R bandwidth of the TES. Post-processing included rejecting time records that contained cosmic-ray events and high pass filtering to reject 1/f noise. The noise itself was characterized by taking the standard deviation of the time record.

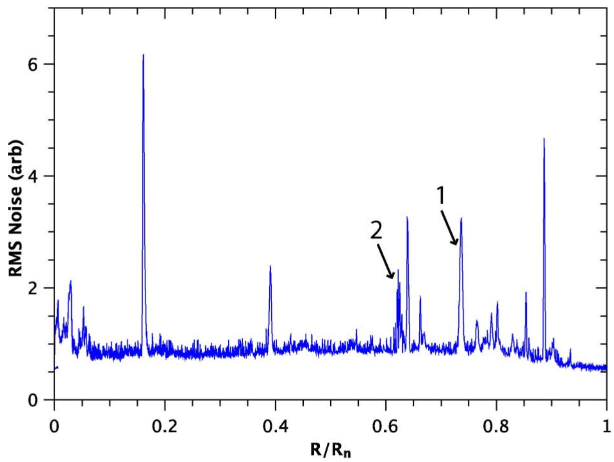

Fig. 1. Standard deviation of the noise records versus fraction of normal state resistance through the superconducting transition. The peaks labeled “1” and “2” are representative of the other peaks and are described in detail in the remainder of this manuscript.

Fig. 1 shows the standard deviation of the noise record as a function of the fraction of the normal-state resistance, R_n. The baseline noise in the transition is higher than the noise in either the superconducting or normal states (not shown). The noise properties in TESs are an area of active research and not completely understood; see discussion by Irwin and Hilton [7] and the references therein. In this manuscript we focus on specific regions of the superconducting transition where there is anomalous noise many times higher than the baseline noise. These regions appear as peaks in the standard deviations of the noise records in Fig. 1. The noise peaks are reproducible in magnitude and location, and are independent of whether the bias current is swept up or down.

Fig. 2 is a magnification of the noise peak labeled “1” in Fig. 1. This peak is representative of most of the other noise peaks observed in the transition and similar noise peaks

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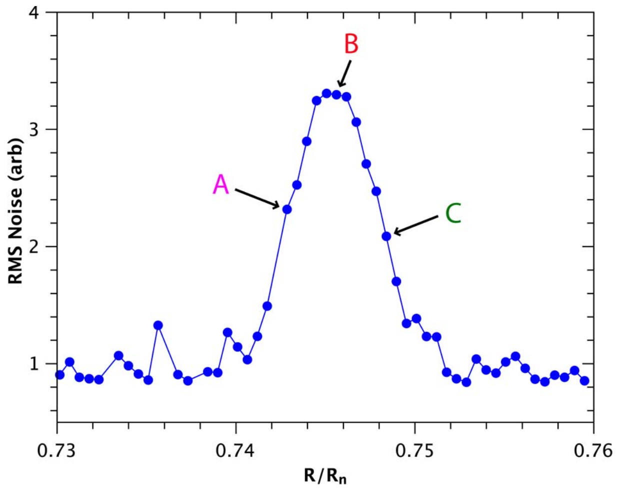

Fig. 2. Expanded plot of peak 1 in Fig. 1 showing finite width of the noise peak. Points labeled A, B, and C are described in the text and in Fig. 3.

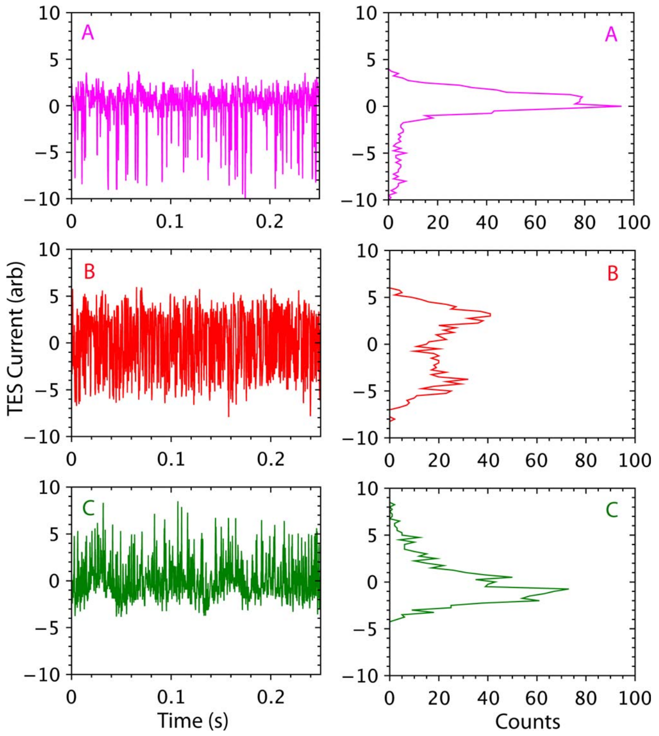

Fig. 3. Time records and amplitude distribution for points A, B, and C from Fig. 2. The data show skewing toward lower amplitude in A, higher amplitude in C, and bimodal behavior in B.

observed in other devices. The peak has finite width roughly on the order of a percent of the transition width. Inspection of the time records and noise amplitude distribution as the bias is swept through the peak reveals a random telegraph signal that switches between two discrete states; see Fig. 3. The histograms of the noise, shown in Fig. 3 on the right, clearly have a bimodal distribution.

In Fig. 3, both points A and C show skewed distributions, with a main peak plus a tail toward the low-amplitude side for A and toward the high-amplitude side for C. Point B shows a time record that at first glance appears to be white, but the distribution clearly show bi-modal behavior. We have inspected time records of five of the largest peaks shown in Fig. 1 and they all show similar behavior. Since positive direction in the amplitude corresponds to increasing current, the tail in Fig. 3 point A on the low-resistance side of the peak is toward lower current, or equivalently, higher resistance, while the tail on the high side of the peak is toward lower resistance. These results suggest that the peaks could be regions within sharp steps in resistance versus bias. However, we have not yet been able to resolve such features in the device current-voltage curve.

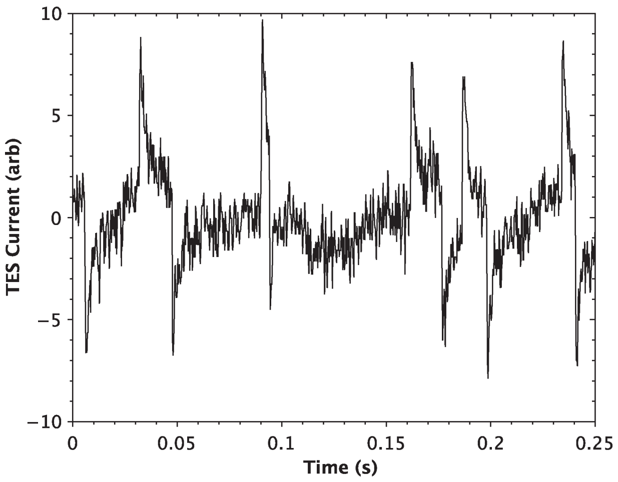

Fig. 4. Time record for peak 2 in Fig. 1, demonstrating a different signature than that seen on most of the other noise peaks.

These noise peaks have been observed in a wide variety of detectors, including gamma-ray and x-ray detectors. Measurements in these other devices with different TESs parameters indicate that the number of noise peaks increases with the current density in the superconducting film. In our x-ray and gamma-ray detectors it is usually possible to choose a bias point where the noise features do not affect the operation of the TES. The high density of the noise peaks in alpha detectors makes them difficult to avoid. Therefore, it is in the alpha detectors where these features have the largest effect on energy resolution.

The behavior observed in these noise peaks is not surprising, considering the complexity of the superconducting transition as a function of both temperature and current. The fact that these noise features appear at discrete points in the transition suggests that they are not caused by normal regions being created by Joule heating of the superconducting film. A standard TES includes normal-metal banks on the sides of the superconducting film to define the superconducting region and normal bars perpendicular to the general current flow to reduce unexplained baseline noise [6]. These features provide multiple current paths and the potential for abrupt switching between them. The discrete noise features could also be caused by changes in dynamic properties in the superconducting film such as phase-slip lines [8], [9] or flux vortices [7].

One of the peaks, peak 2 in Fig. 1, shows an additional behavior. The time record shown in Fig. 4 has an associated decay with each jump in noise, with a decay time similar to the decay time of the detector pulse response. This response is characteristic of the large heat capacity of the TES, the thermal conductance of the SiN membrane, and the strength of the electro-thermal feedback [7], [10], and is suggestive of a thermal component to the noise spikes.

In conclusion, we observe bias-specific noise features in TESs that have a bimodal distribution. The noise features are suggestive of thermally activated switching across a jump in the resistance in the superconducting transition. This anomalous noise has a strong effect on the energy resolution of TESs, especially when the pulse excursions sample one or more of the noise regions. More studies are necessary to identify the origin of these features and to design a device that either eliminates them or moves them to a region of the transition where they do not degrade energy resolution.

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