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# Telegraph Noise Spectroscopy of Submicron Ta/PbBi Junctions

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We report on the noise properties of Ta-Ta oxide-$Pb_{0.9}Bi_{0.1}$ tunnel junctions of area 0.2-1 $\mu m^2$ and resistance $R_N \sim$15-300 Ω in the frequency range 1 Hz to $10^5$ Hz. The noise power spectrum displays one or several distinct Lorentzian peaks associated with the observed switching of the junction resistance between discrete levels. The switching rates increase with temperature and bias voltage and are unaffected by an applied magnetic field of up to 50 kGauss.

## 1. INTRODUCTION

The investigation of the low frequency noise properties of electronic devices is essential to understanding the physical origins of fluctuation phenomena, and can lead to improvements in the performance of devices such as SQUIDs, MOSFETs, and diodes. Recent studies [1-3] of submicron devices have revealed a telegraph-like pattern of fluctuation arising from a single trap. Rogers and Buhrman [1] first reported such noise in superconducting tunnel junctions of small area. They also set the framework for the study of the trap kinetics involved, termed "Telegraph Noise Spectroscopy". Similar observations are reported in DC SQUIDs [2].

We have studied the noise properties of Ta-Ta oxide-PbBi tunnel junctions of area 0.2-1 $\mu m^2$. Similar junctions of slightly larger area have shown extremely low leakage currents [4,5] and are useful as SIS mixers [5]. We report here the observation of discrete switching of the resistance of these junctions and discuss the dependence of this behavior on temperature, voltage, and applied magnetic field. We also attempt to correlate these observations with another barrier spectroscopy based on measurements of the differential conductance [6].

## 2. EXPERIMENTAL DETAILS

The Ta base electrode is deposited by ion-beam sputtering and patterned by photoresist lift-off. A window opening in a deposited SiO layer defines the junction area. The window diameter can be made as small as 0.5 $\mu$m by projection photolithography, yielding a junction area of $\sim$ 0.2 $\mu m^2$. Ion-beam cleaning is used prior to an oxygen dc glow discharge oxidation, which forms a high quality tunnel barrier. The counter-electrode consists of 3000 Å of $Pb_{0.9}Bi_{0.1}$ which is coated with 120 Å of Indium. We find that the resistance and quality of such In-coated junctions are insensitive to air exposure. Junctions without the In coating show an increased resistance ("aging") upon exposure to air.

We characterize the junctions by measuring their I-V characteristics and dV/dI by standard ac modulation techniques. To measure the noise power spectral density, the junction is current biased using a low-noise current source [7]. The junction voltage is amplified by a low-noise pre-amplifier (Analog Devices AD-624C) with a noise voltage above 10 Hz of 4 nV/$\sqrt{Hz}$. The output of the amplifier is then sent to an HP3561A signal analyzer

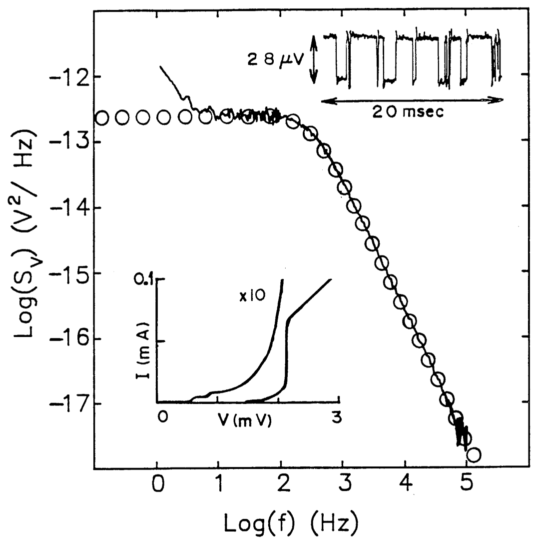


Fig. 1. Power Spectral Density dominated by the two-level switching of a single trap (shown in top inset). O is a fit using Eq.1., $\delta V$=28 $\mu$V, $\tau_{up}$=1.7 msec, $\tau_{down}$=0.54 msec, all measured from the time trace. T=4.2 K, $R_N$=250 Ω, $V_{dc}$=25 mV, A=0.2 $\mu m^2$. Bottom inset shows a typical I-V of a similar junction with current density $\sim 10^5$ A/cm$^2$.

which measures the power spectral density in the range 1-$10^5$ Hz and also acts as digitizing oscilloscope.

## 3. RESULTS AND DISCUSSION

At certain bias levels, in the current range 0.1-3 mA and the voltage range 10-250 mV, the noise power spectrum displays one or several distinct Lorentzian peaks. These peaks are associated with the observed switching of the junction resistance between two or more discrete levels. The switching corresponds to a relative change in resistance $\delta R/R \sim 10^{-3}$ - $10^{-4}$. Fig. 1 shows the power spectral density in a situation where the excess low frequency noise is dominated by the telegraph-like voltage fluctuation shown in the inset. By collecting a sequence of such time traces and measuring the distribution of times spent in the high-resistance state ($t_{up}$) and low-resistance state ($t_{down}$), we find that each of these times is exponentially distributed: this is evidenced by the fact that the average (e.g. $\langle t_{up} \rangle = \tau_{up}$) is equal to the standard deviation $\sigma_{up}$ of the distribution and by the fact that a histogram shows an exponential distribution with a slope equal to both $\tau_{up}$ and $\sigma_{up}$, within a few percent. By determining $\tau_{up}$ and $\tau_{down}$ as described and measuring the voltage jump $\delta V$, we can calculate the power spectral density due to this random switching sequence using the following equations of Machlup [8] for a random telegraph signal:

$$1/\tau = 1/\tau_{up} + 1/\tau_{down} \quad (1a)$$

$$S_V = 4(\delta V)^2[\tau/(\tau_{up} + \tau_{down})][\tau/(1 + \omega^2\tau^2)] \quad (1b)$$

The fit to Eq. 1 is shown in Fig. 1. It demonstrates clearly that the excess low frequency noise arises from the random switching of a single trap.

For a given junction, we observe switching only for certain values of the bias voltage. When switching is observed, increasing the bias voltage causes the switching rate to increase. This increase of rate continues until the rate exceeds the bandwidth of the measurement system. The dependence of the rate ($\tau^{-1}$) on bias voltage is approximately exponential. This is illustrated nicely in Fig. 2 which shows a series of power spectral densities for the same junction where only the bias voltage is varied. The knee in the Lorentzian occurs at a frequency proportional to the effective rate. The temperature dependence we observe is consistent with the observations of Rogers and Buhrman [1]: from about 10 K to 77 K the rates vary exponentially with 1/T, and below 10 K the rates are approximately temperature independent.

We observe a range of switching rates corresponding to average lifetimes of 0.1-100 msec. For each junction the switching is observed at different bias voltages. The configuration of traps causing the switching changes if the junction is either warmed to room temperature or subjected to large bias voltages ( > 300 mV). We observe one or more two-level switching events, and in a few rare cases a three-level sequence occurs. The observed rise-time and decay-time of the switching in most cases are limited by the time constant of the instrumentation, but in a few cases we clearly observe a finite extent to the rise or decay.

Rogers and Buhrman [1] have proposed a model explaining the microscopic origin of the switching events by the trapping and untrapping of single electrons into localized defect states within the tunneling barrier. Within this model, the deviation of the rates from thermal activation below about 10 K is attributed to transitions between ionic configurations via ionic tunneling. Our observations are consistent with this model. To gain further insight into the microscopic mechanisms involved we have studied the effect on the switching of an external magnetic field applied parallel to the plane of the junction. We find that, up to 50 kGauss, no measurable effect is observed in either the magnitude or the rates of the switching.

A different probe of localized states in a tunnel barrier is the differential conductance dI/dV. As in larger area junctions [9], we observe in the small junctions excess conductance in the bias voltage range 40-100 mV. This excess conductance manifests itself more clearly as a broad peak in the logarithmic derivative d[ln(I/V)]/dV; each peak indicates the onset

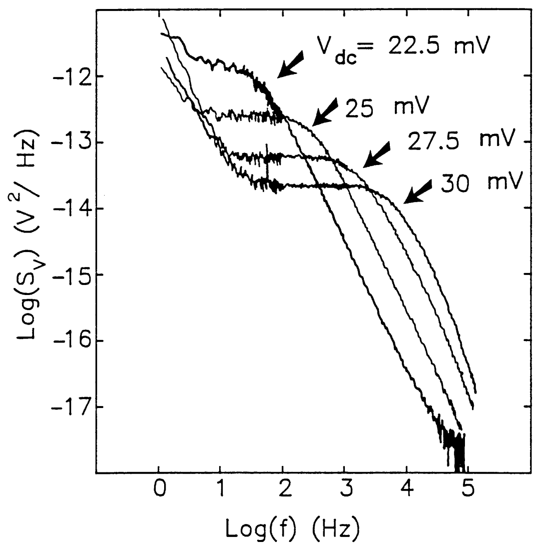


Fig. 2. Power Spectral Density at different bias levels. $R_N$=250 Ω, T=4.2 K The switching rate increases exponentially with voltage.

of new conductance channels associated with localized states in the barrier [6]. The ac modulation voltage used in measuring dI/dV is typically much larger than the magnitude $\delta V$ of the telegraph noise. When we decrease this ac modulation to a level smaller than $\delta V$, we observe telegraph noise in the same voltage range where the excess conductance is observed. This is an indication that the same localized states giving rise to the excess conductance may be undergoing bi-level transitions which cause the telegraph noise. We will discuss these results further in a future publication.


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