Standard deviation of the switching supercurrent in graphene proximity junctions

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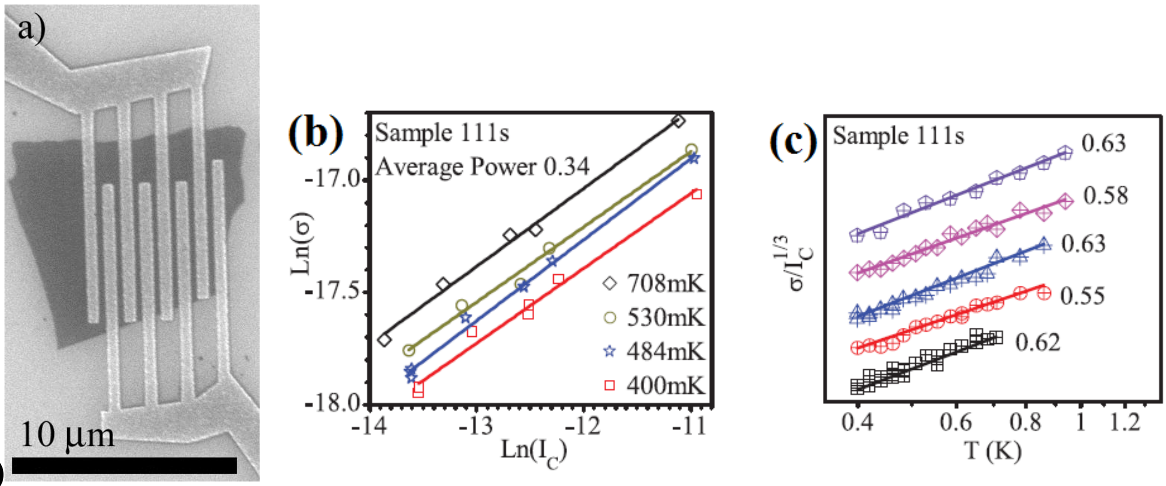
Measurements of the decay statistics of metastable states is a powerful tool for revealing the intrinsic thermal and/or quantum fluctuations of the nano-scale system. In the Josephson junctions (JJ) a metastable dissipationless (superconducting) state decays into dissipative (phase slippage) state when the bias current, *I*, reaches so-called called switching current, *Isw*, which is stochastic. Analysis of the distribution of the switching current was employed to reveal macroscopic quantum tunnelling in magnetic nanoparticles, JJs, superconducting nanowires, and intrinsic JJs in high-T_c compounds. Experimentally observed temperature dependence of the switching current standard deviation, sigma, obtained by measuring the switching current many times on the same sample, always follows a power law, *sigma~T*^{2/3}, if the switching is induced by a single thermally activated escape from the metastable state. However, at sufficiently low temperatures, the temperature dependence of sigma saturates, which is usually attributed to macroscopic quantum tunnelling. In general, any power law different from 2/3 is associated with the possibility of quantum phase slips.

We investigate the stochastic nature of switching current of superconductor-graphene-superconductor (SGS) junctions with large critical currents, achieve by a “finger” geometry of the junction (Fig.1a). To make samples, graphene flakes are deposited on 280 nm thick SiO_2 on the Si chip surface using mechanical exfoliation, using the Novoselov-Geim method. Raman spectroscopy is used to confirm the number of layers. The electrodes, which have a fingered shape (Fig. 1a), are patterned from a bilayer Pd/Pb (4nm/100nm).

We find that the standard deviation¸ *sigma*, of the switching current distribution scales with temperature as *sigma~T^alpha*. The power, *alpha*, of the power law temperature dependence of the standard deviation can be as low as 1/3 in graphene junctions [1]. This observation is in sharp contrast with the known JJ behavior in which alpha=2/3, as predicted by Kurkijarvi [2]. We find an explanation to the observed unusual power alpha within the Kurkijarvi theory itself, which we modify appropriately to apply to our current-biased junctions. In fact, the power law in the theory is dependent not only on temperature by also on the critical current. In tunnel junctions with superconducting electrodes the critical current is not temperature dependent at low temperatures. But, in proximity junctions [3] (called superconductor-normal-superconductor or SNS) the temperature dependence of the critical current persists, in theory, down to zero temperature. According to Kurkijarvi, *sigma* scales with the critical current as sigma~*Ic*^{1/3}. We check this explicitly, probably for the first time, using the gate voltage control, which allows us to vary *Ic* in a wide diapason. The result is presented in Fig.1b. Thus, as it is established that sigma scales with the critical current as expected from the Kurkijarvi theory, we look into the main result of the theory, namely that *sigma~T*^{2/3}*Ic*^{1/3}. From this it follows that the power of 2/3 should be recovered if *sigma*, normalized by the temperature-dependent critical current as *sigma/Ic*^{1/3}, is plotted versus T. This is indeed the case as is shown in Fig.1c. The power observed there is close to the expected 2/3. Some fluctuations of the power with the gate voltage remain unexplained.



(a)

Figure 1. (a) *A scanning electron microscope (SEM) micrograph of a "fingured" graphene junctions. Such design allows us to increase the critical current compared to straight junctions by a large factor. The electrodes (fingers) are made of Pd (4 nm) and Pb (100 nm). Lead is used as the material for the electrodes since it provides strong superconducting proximity effect [3] into graphene. The distance between the electrodes is about 300-400 nm. The accumulative length of the junctions varies from sample to sample and can be as long as 200 microns. Thus the fingered design allows us to obtain extra-long junctions.* ***(b)*** *Logarithm of the standard deviation of the switching current plotted versus the logarithm of the critical current. The scaling with the power of 0.34 is observed. This is in agreement with the Kurkijarvi theoretical prediction [2] that such power should be 0.333. (c) Normalized standard deviation plotted versus temperature. The power is about 0.6, which is close to the theoretically expected 2/3. Some fluctuations of the power with the gate voltage, which is the parameter for these curves, is not well understood currently.*

References

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