Superconductor to Insulator transition in (111) $SrTiO_3/LaAlO_3$ interface.

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Introduction

The superconductor to insulator (SIT) transition is a prototypical quantum phase transition where the ground state of a 2D system transitions from a superconductor into an insulator upon changing a control parameter such as film thickness, disorder or magnetic field. Many scenarios have been put forth to explain the SIT: dominating fermionic physics after the breaking of Cooper pairs, loss of phase coherence between superconducting islands and localization of Cooper pairs with concomitant condensation of vortex-type excitations. The difficulty in characterizing the insulating state and its origin stems from the lack of a continuous mapping of the superconducting to insulating phase diagram in a single sample.

Experimental

We used SCM1 to measure the sheet resistance as a function of magnetic field applied parallel and perpendicular to the interface at base temperature. The sample sheet resistance was tuned using gate voltage. Additional measurements were taken at Tel Aviv University up to 9 Tesla.

Results and Discussion

To further understand the origin of the SIT, we performed magnetic field sweeps in parallel and perpendicular orientations (see **Fig.#1**). First, we note that the high field magnetoresistance is isotropic, suggesting an absence of orbital effects in the normal state. This is contrasted with the highly anisotropic behavior at lower fields, where fluctuations can still survive. The observed anisotropy supports the idea that the effect seen under perpendicular fields is caused by vortex excitations.

We identify a new magnetic field scale, $H_{pairing}$, where superconducting fluctuations are muted and find a length scale ξ_{ins} interpreted as the size of the vortex fluctuation in the insulating state. Our findings suggest that vortex fluctuation excitations and Cooper pair localization are responsible for the observed SIT and that these excitations surprisingly persist deep into the insulating state.

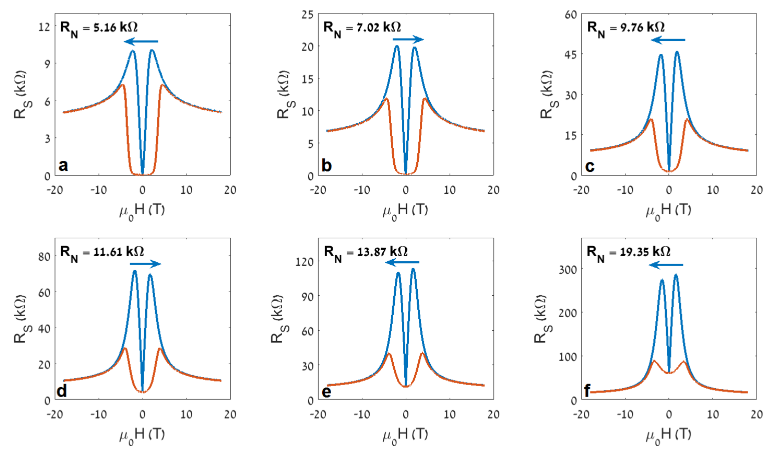

Fig.1 Sheet resistance measured at 21 mK plotted against magnetic fields perpendicular (blue) and parallel (red) to the sample surface for six different gate voltages (labeled according to their sheet resistance at 800mK R_N). The small asymmetry in the magnetoresistance peaks observed for perpendicular field orientation is related to the sweep direction (indicated by the blue arrows).

Conclusions

We observe a gate-controlled transition from the superconducting to the insulating state at the quantum resistance similar to the hallmark data of Haviland Liu and Goldman [1]. We use the comparison of measurements in parallel and perpendicular field to define and follow a new energy scale related to the depairing field $H_{Pairing}$. The linear field dependence of the magnetoresistance at low fields {with the resulting values of the coherence length}, the strong anisotropy of the magnetoresistance at the peak region and the hysteresis of the peak all are evidence that this peak is related to the formation of a liquid of vortex excitations. Our data present the continuous evolution of a variety of phenomena observed, until now, in many different samples and regimes and show that vortices play an important role in the insulating state observed beyond the superconductor-to-insulator transition in this material [2].

Acknowledgements

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References

[1] D. B. Haviland, Y. Liu, and A. M. Goldman, *Phys. Rev. Lett.* **62**, 2180 (1989)
[2] M. Mograbi, M., E. Maniv, P. K. Rout, D. Graf, J-H. Park, and Y. Dagan. *arXiv preprint arXiv:1805.09574* (2018).