Detection of flux-quantized vortices in ordered graphene Josephson junction arrays

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Patterning graphene with superconducting contacts enables Dirac fermion supercurrents to flow for several hundred nanometres via proximity-induced Andreev bound states [1], and for several millimetres in long junctions decorated with disordered arrays of superconducting islands [2, 3]. The strong appeal of using graphene as a superconducting weak link is the ability to engineer the properties of the junctions by tuning the normal-state resistance and phase coherence length using the electric field-effect from nearby gates. Such tunability is particularly desirable for voltage-controlled manipulation of single flux quanta topologically confined in ordered arrays of Josephson junctions, which has relevance to low-power high-speed rapid single flux quantum logic, and quantum information processing with flux qubits.

We experimentally detect flux-quantized Josephson vortices - whirlpools of supercurrent induced by an applied magnetic field – as they penetrate an ordered Josephson junction array formed by patterning superconducting disks on monolayer graphene [Fig. 1(a)]. The proximity effect due to the disks and contacts enhances the conductance of the device below the critical temperature and field of the superconductor, while the pinning configurations of the penetrating vortices are revealed through kinks in the magnetoresistance whenever the magnetic field generates an integer number of flux quanta through the array [4]. The observed matching fields are in excellent agreement with Ginzburg-Landau calculations [5] simulating the magnetic field dependence of the ground state vortex configuration and critical current [Fig. 1(c, d)].

Our devices offer a convenient way to explore the phase diagram of Josephson vortex matter in graphene, to incorporate flux-quanta in graphene-based nanoelectronic and spintronic devices, and to realize novel quantized voltage sources for complementing recent work on graphene-based resistance and current standards.

References

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Figures

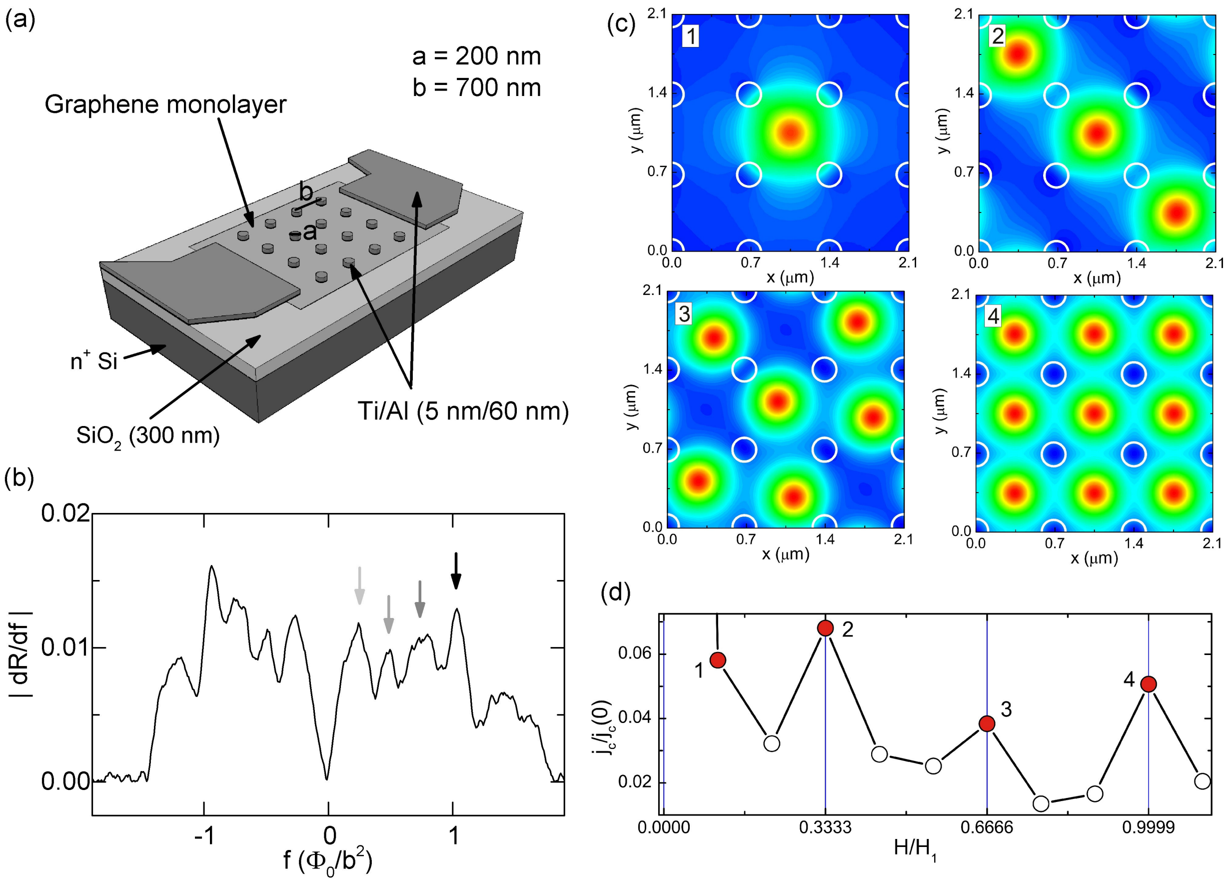

Fig. 1. (a) Device schematic, *a* is the disk diameter and *b* the centre-centre separation. (b) Absolute derivative of the array resistance, normalised to the normal state value, as a function of frustration, *f*. Arrows correspond to approximate fields used to calculate vortex positions in (c). (c) Snapshots showing the superconducting order parameter |*Ψ*| (red is low, blue is high), calculated within the Ginsburg-Landau formalism. (d) Calculated critical current as a function of frustration. Red circles correspond to panels in (c).