Novel Josephson effects in superconductor-semiconductor systems

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Superconducting nanostructures underpin the development of many promising quantum computing approaches and alternatives to conventional classical computing. Most work to date has focused on all-metallic Josephson junctions. Recent developments in materials synthesis and nanofabrication have enabled devices that combine superconducting and semiconducting properties. These provide new opportunities for science and technology that rely on the interplay between superconductivity, quantum confinement, ballistic transport and spin-orbit coupling, or which leverage gate-tuning of superconducting couplings. In this talk, I will present results from a few transport studies based on semiconducting nanowires and quantum wells coupled with superconductors. The talk will focus primarily on nanostructures with more than two superconducting terminals [1-4], which can be used to implement superconducting diodes and non-linear intermodulation with full electrostatic control or to realize unusual correlations between Cooper pairs, and could also serve as a platform for topological Josephson matter [5].

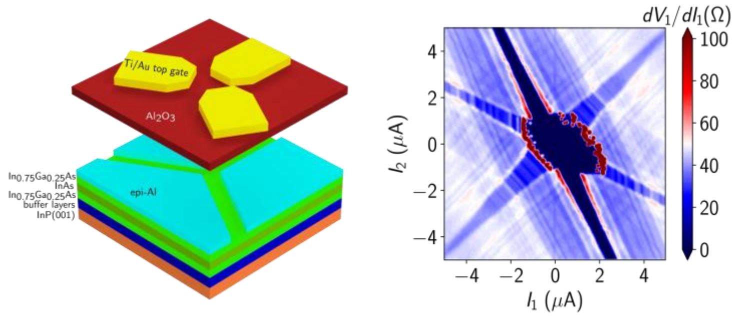

Figure 1. (left) Schematic of gated Josephson device based on an InAs quantum well with epitaxial Al. (right) Measured stability diagram showing different transport regimes of a three-terminal Josephson junction based on the system described in (left).

[1] M. Gupta *et al.*, arXiv:2312.17703 (2023).
[2] M. Gupta *et al.*, Nature Communications **14**, 3078 (2023).
[3] G. Graziano, M. Gupta *et al.*, Nature Communications **13**, 5933 (2022).
[4] G. Graziano *et al.*, Phys. Rev. B **101**, 054510 (2020).
[5] R. Riwar *et al.*, Nature Communications **7**, 11167 (2016).

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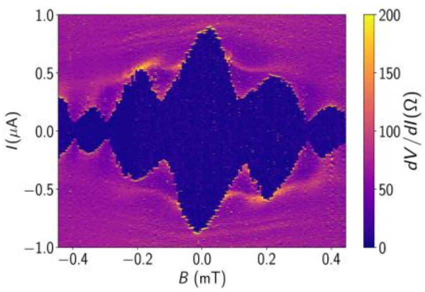
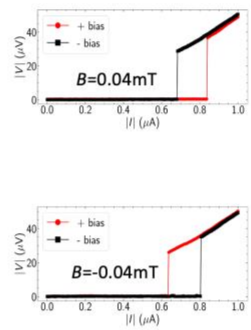
Suplementary Pages (Optional)

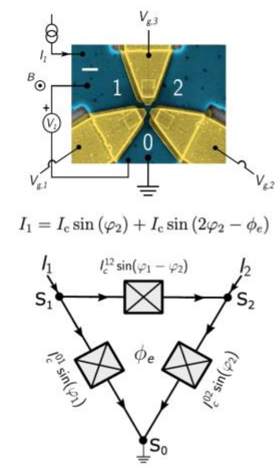
The images below show more details about the super-semi nanostructures and novel transport effects measured thereon, that will be presented in the talk.

Gate-tunable Josephson diode using MTJJs

- Interference pattern is anti-symmetric in magnetic field and current
- The asymmetry is tunable by out-of-plane magnetic field
- Operates in effectively zero B-field
- Material-independent superconducting diode based on current-phase relations with higher harmonics

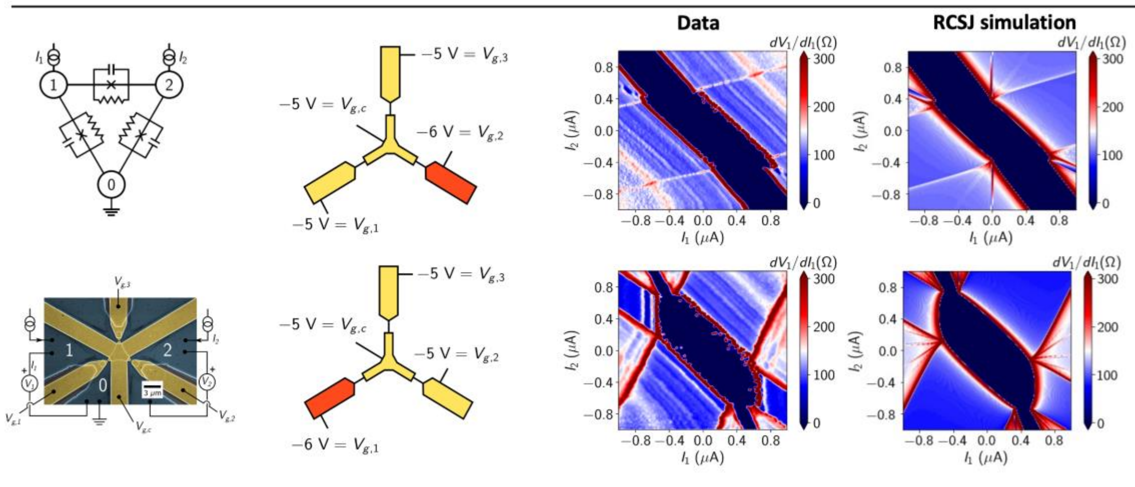






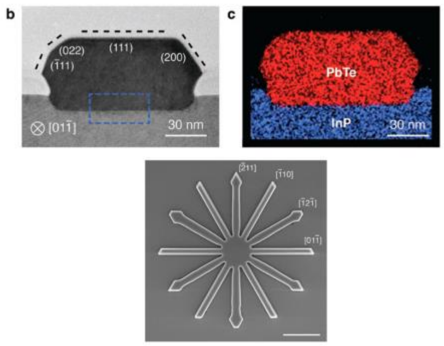
M. Gupta, … VSP, Nature Communications 14, 3078 (2023).

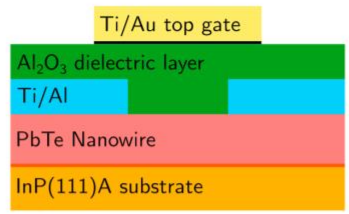
Selective control of conductance in each leg



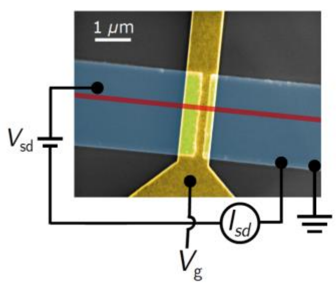
- Agreement with RCSJ network model simulations
- Equivalence to a network of two-terminal Josephson junctions

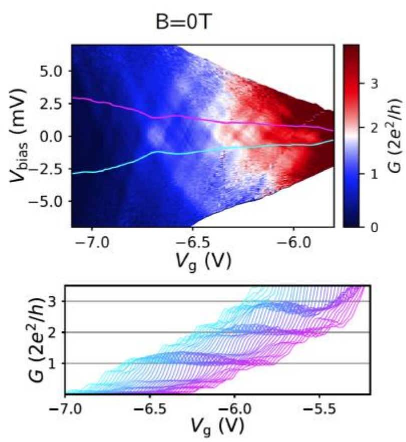
Selective-Area Grown PbTe Nanowires with aluminum contacts

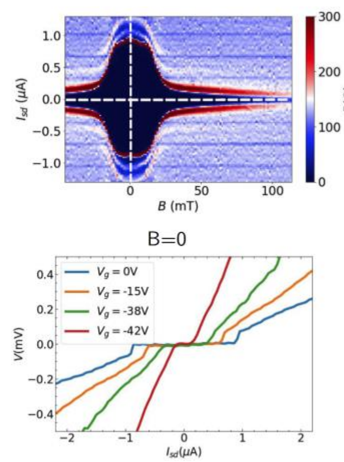




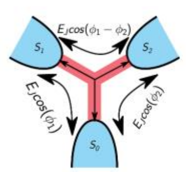
Bakkers group, *Adv. Funct. Mater.* **32**, 2208974 (2022)



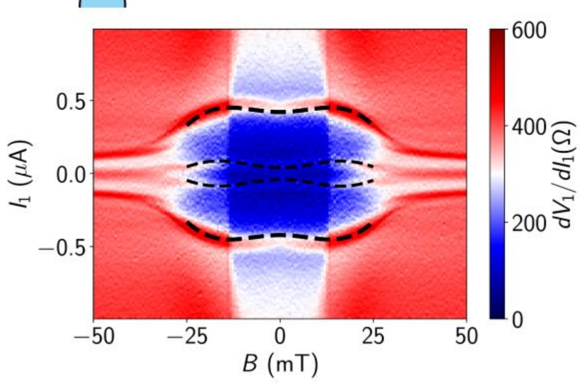




Experimental quartet detection



Data Fitted with Josephson energy containing contribution from three-terminal processes



Dashed black lines are fit to:

$$I_c(\Phi) = \frac{4e}{\hbar}|E_J \cos(\Phi/2) + E'_J \cos(3\Phi/2)|$$

E'_J → quartet contribution

M. Gupta, ..., V. S. Pribiag, arXiv:2312.17703 (2023).