Ultrafast electronics on chip

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Abstract

Ultrafast dynamic control of quantum matters has met big success in the last decade in light of the development of ultrafast laser techniques. The emergent non-equilibrium phenomena arise at femto to picosecond timescales which are intrinsic to the microscopic interaction between electron, spin and lattice, and provide the possibilities to achieve faster electronics on chip. So far, these photo-induced phases have been mainly characterized by optical, scattering, scanning and photoemission techniques [1]. On the other hand, the corresponding transport responses namely voltage or current signals, which are directly related with the performance after integration into electronic circuits, are largely unexplored yet.

Here we combine THz waveguide and photoconductive switches to fabricate ultrafast electronics on chip with sub-picosecond time resolutions [2]. We use this platform to probe the transient electrical responses from photo-induced superconducting-like state in an organic superconductor K_3C_{60}. Two experiments have been conducted. In the first experiment, sub-picosecond current pulses were launched and guided through the K_3C_{60} thin film sample [3]. By measuring the transmittace of the current pulses, we observed the drop of resistance and nonlinear voltage-current behavior in optically driven K_3C_{60} at temperature above the equilibrium T_c. This behavior resembles an equilibrium granular superocnducotr. In the second experiment, we developed an on-chip ultrafast voltmeter platform to study the voltage dynamics across optically driven K_3C_{60} in presence of current [4]. We observed fast changes associated with the kinetic inductance of in-grain superconductivity, and a slower response attributed to the Josephson dynamics at the weak links.

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References

1. de la Torre, A., et al., *Colloquium: Nonthermal pathways to ultrafast control in quantum materials.* Reviews of Modern Physics, 2021. **93**(4): p. 041002.
2. McIver, J.W., et al., *Light-induced anomalous Hall effect in graphene.* Nature Physics, 2020. **16**(1): p. 38-41.

3. Wang, E., et al., *Superconducting nonlinear transport in optically driven high-temperature K3C60.* Nature Communications, 2023. **14**(1): p. 7233.
4. Adelinia, J.D., et al., *Probing photo-induced granular superconductivity in* K_3C_{60} *thin films with an ultrafast on-chip voltmeter.* arXiv preprint arXiv:2312.06421, 2023.