Transparent superconductors for single-photon detectors

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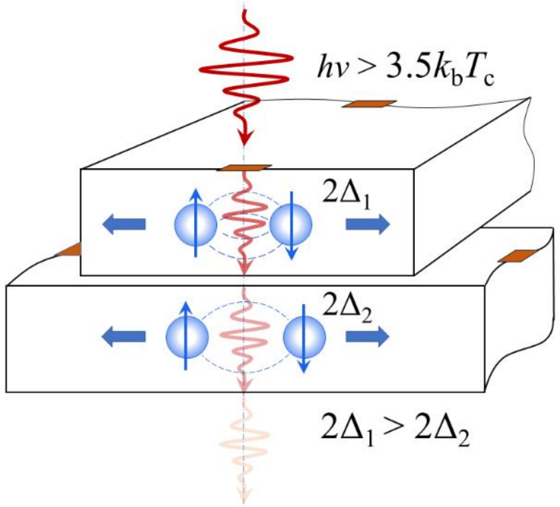
Transparent superconductor: Cooper pairs interact with a single photon through the whole thickness of the film. The low energy photons pass through the first layer (if $h\nu < 2\Delta_1$) and interact with Cooper pairs of the second layer having lower band gap ($h\nu > 2\Delta_2$).



Research Objectives

- *Develop Transparent superconductors* (TSCs) based on a series of transparent electronic conductors (ITO, TiO_x, ZnO_x, WO_3.) electrochemically intercalated with alkali ions.
- *Develop Single-photon detectors* (SPDs) working in space environments. Passive matrix SPDs sensitive to the polarization of light with high selectivity for specific wavelengths of incident light (spectrometers).
- *Demonstrate enhanced optical transparency* and *reduced Joule heating* caused by excitation of free conduction band electrons that do not participate in the superconducting (SC) state.
- *Demonstrate SPD with enhanced sensitivity* and reduced relaxation time, timing jitter, and signal-to-noise ratio of the SPD.
- Study self-healing abilities of TSCs for increased tolerance to radiation damage in space environments.
- Project is currently at TRL 2 and expect to reach TRL 5 by the end of the award.

Approach

- This work proposes a novel route to fabricate and design SPDs by *replacing* conventional SC *metals and metal-alloy films* with thin films and nanowire arrays of *transparent superconductors* (TSCs): (1) Sputtering a thin oxide film, (2) Thermal annealing to achieve the desired crystallinity, (3) Printing photoresist patterns onto the TSC film, (4) Electrochemical intercalation of the exposed surface to the optimal charge density providing the desired T_c, (5) Post-annealing to enhance film homogeneity.
- The SPDs will be characterized using traditional structural and imaging analysis (SEM, TEM and EDX) paired with XRD, XPS, FT-IR, Raman spectroscopy. The interaction of single photons with SPDs will be performed in an optical cryostat equipped with a UV-vis-NIR spectrometer. Transport properties and mechanism of superconductivity for intercalated TSCs will be studied experimentally (PPMS and MPMS) and theoretically.

Potential Impact

- The SPD based on TSCs will provide higher sensitivity, signal-to-noise ratio, and lower relaxation time. The large surface area matrices will provide imaging capabilities while 3D layered design can provide photon energy selectivity.

- The TSC technology will pave the way for new functionalities such as a nonlinear interaction of the Cooper-pair condensate with incident light: (i) The long optical pathway can mediate a strong coupling of a pair of single photons, making this “collective particle” important for quantum informatics. (ii) The TSC medium enables the entanglement of micro-waves with a carrier optical wave passing through the SC quantum state, which provides a route to efficiently link up hybrid quantum systems.