Enhancing Optical TESs performances for PNR-detector array development

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Abstract: The STAR project develops scalable Transition-Edge Sensor arrays for quantum photonics. Using optimized thin films and anti-reflection coatings, these detectors achieve >80% efficiency, 13-photon resolution, and >1 MHz rates, integrating a novel fiber-coupling alignment system.

Photon-number-resolving (PNR) detectors are a key enabling technology for quantum photonics, with applications in quantum communication, computing, and metrology. Superconducting Transition-Edge Sensors (TESs) are among the most promising candidates due to their intrinsic energy resolution and high detection efficiency. However, scaling TES devices into arrays compatible with fiber-coupled and integrated photonic platforms remains a significant challenge.

The STAR project addresses these limitations through the development of TES-based detector arrays with optimized performance and scalable optical interfacing. TES devices were fabricated using Ti/Au and Ti/Au/Ti thin films with critical temperatures in the range 167–287 mK. The fabrication process was refined to improve device uniformity and lithographic precision, enabling the realization of a linear array of eight TES pixels with 250 µm pitch, specifically designed for direct coupling to standard optical fiber arrays.

To enhance optical absorption, anti-reflection coatings (ARC) and optical cavity structures were designed and characterized. ATi/Au/Ti TES with ARC showed a system detection efficiency above 80% at 690 nm [1]. In addition, detailed simulations on different layouts demonstrate absorption exceeding 90% at target wavelengths around 790 nm, with reflection losses reduced below 5% over a broad spectral range (720–980 nm). These results confirm a clear path toward system detection efficiencies above 90%.

State-of-the-art photon-number resolution was achieved, discriminating up to 13 photons at 690 nm with a resolving power of $E/\Delta E \sim 4$ (Fig. 1 Left). Furthermore, adding Au banks to the TES resulted in fast detector dynamics, yielding an effective time constant of 340 ns and repetition rates exceeding 1 MHz (Fig. 1 right).

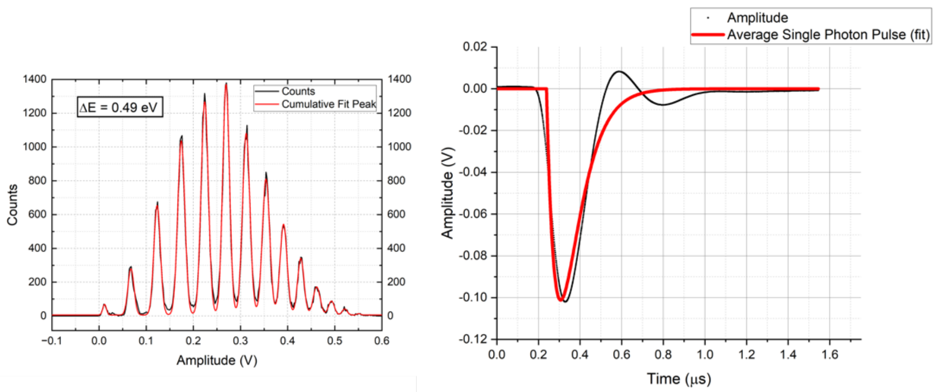

Fig. 1 Left: Amplitude histogram of 690 nm laser pulses detected by a high-efficiency Ti/Au/Ti TES with ARC**. Right:** Averaged single-photon pulse detected by a Ti/Au TES showing a decay time of 68 ns.

A major innovation of the project is the development of POLARIS (Precise Optical Line-up And Reference Imaging System), a dedicated alignment facility combining infrared imaging, a hexapod positioning system, and automated image-processing algorithms. This system enables precise and reproducible alignment of optical fiber arrays to TES arrays, overcoming a critical bottleneck for scalability and practical deployment.

The combination of high efficiency, fast response, and scalable array architecture establishes TES technology as a strong candidate for integration into next-generation quantum photonic platforms.

[1] F. Malnati et al. "Optimizing optical TESs for high-efficiency Multimode Fiber coupling", accepted for publication on IEEE TAS (2026).