

Thesis title: Innovations in Transition-Edge Sensors as superconductive single-particle detectors

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Abstract:

This thesis presents a comprehensive study on Transition-Edge Sensors (TESs), superconducting detectors with single-particle sensitivity, focusing on their design, fabrication, modeling and optimization for both photon and electron detection.

The introductory chapter outlines the operational principles of TESs, introducing the electro-thermal feedback model and including the two-fluid and weak-link models. A comparative analysis of the main superconducting photon detectors—TESs, Kinetic Inductance Detectors (KIDs) and Superconducting Nanowire Single-Photon Detectors (SNSPDs) concludes the chapter, contextualizing the specific advantages of TES technology.

Chapter 2 details the microfabrication processes developed for TES devices, focusing on the core steps of photolithography, thin-film deposition and patterning. The experimental setups for morphological, electrical and optical characterization are also described.

In Chapter 3, the research addresses the development of fast-response detectors within the framework of the SEQUME project. Aluminum-based TESs are investigated for their high-speed potential, highlighting challenges related to fabrication reproducibility. To effectively accelerate the thermal response, the integration of lateral gold banks on standard TiAu TESs is explored. The results demonstrate that this geometric modification significantly reduces the recovery time to the order of hundreds of nanoseconds, even if “bumps” in the pulse shape have been observed and modeled using a multi-body thermal framework.

Chapter 4 presents a preliminary study on the application of TESs for single-electron detection within the PTOLEMY project context. The challenges related to scattered and secondary electron (SE) emission and backscattering are discussed, with kinematic estimates suggesting that flight times are very fast compared to the detector response and do not allow discrimination of the SEs from their primary electron. Simplified geometrical considerations are then applied to modeling the collection probability of scattered electrons, offering initial design guidelines to improve efficiency.

In Chapter 5, the longitudinal proximity effect induced by the wiring on the TES bilayer is investigated. Systematic measurements of the critical temperature and transition width are conducted on strips with varying lengths and wiring materials (Nb, Ti, Al). The study evaluates different configurations, including the use of a top Titanium layer, which is shown to effectively suppress the longitudinal proximity effect.

Chapter 6 addresses the enhancement of photon detection efficiency. Anti-reflection (AR) coatings fabricated achieve measured efficiencies up to 85%. Furthermore, the potential of plasmonic metasurfaces is explored with many structures as COMSOL simulations as an alternative absorption strategy; numerical simulations of optical micrometric gratings are presented alongside ellipsometric characterization of test structures with reflectivities as low as 5%.

Supplementary material, including the fundamental theory on superconductivity, SQUIDS and detailed fabrication and measurement procedures is provided in the Appendices. This work contributes to the technological advancement of TESs at INRiM, pushing the boundaries of high-efficiency single-particle detection and temporal resolution necessary for quantum technologies and fundamental physics experiments.