Quantum Efficiency Characterization and Optimization of a Tungsten Transition-Edge Sensor for ALPS II

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Abstract The ALPS II experiment, Any Light Particle Search II at DESY in Hamburg, will look for sub-eV mass new fundamental bosons (e.g., axion-like particles, hidden photons, and other weakly interacting sub-eV particles) in the next years by means of a light-shining-through-wall setup. The ALPS II photosensor is a tungsten transition-edge sensor (W-TES) optimized for 1064 nm photons. This TES, operated at 80 mK, has already allowed single infrared photon detections as well as non-dispersive spectroscopy with very low background rates. The demonstrated quantum efficiency for such TES is up to 95 % (1064 nm) as has been already demonstrated by the US National Institute of Standards and Technology. A back-to-back measurement of the ALPS TES quantum efficiency using a calibrated charge-coupled device camera has lead to a first estimation of 30 %. Improvement methods are discussed.

Keywords Transition-edge sensor · TES · Detection efficiency

1 Introduction

The ALPS II experiment will be looking in the next years for new sub-eV mass fundamental bosons by shining light through a wall [1]. The general setup consists of an infrared laser (1064 nm), two optical cavities separated by a light-tight barrier and a single-photon detector. Photons stored in the cavity located beforehand the wall could convert into beyond the Standard Model particles which traverse the barrier before

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converting back into photons that would be detected. Due to the photons low energy (1064 nm, i.e., 1.17 eV) and the expected low rate of one photon every few hours, such detection represents many technical challenges.

As single infrared photon detector, the ALPS collaboration chose a tungsten transition-edge sensor developed by NIST. Such detectors have been demonstrated to have a high quantum efficiency ($>95\%$ [3]) as well as a very low intrinsic dark count rate of 10^{-4} s^{-1} [2]. In addition to these two essential parameters, TESs have a long-term stability, a good energy resolution ($<8\%$), as well as a good time resolution [2], meeting all ALPS criteria.

2 Single Infrared Photon Detection System

Transition-edge sensors are superconductive microcalorimeters measuring the temperature difference ΔT induced by the absorption of a photon. The positioning of the detector within its superconductive transition (30% of its normal resistance) is induced through a thermal link to a heat bath at $T_b = 80 \text{ mK}$ and through a constant bias voltage. The ALPS detector module includes two TESs inductively coupled to a superconducting quantum interference device (SQUID).

The ALPS detectors are optimized for 1064 nm photons. The tungsten (W) layer is surrounded by an antireflective coating (aSi, amorphous silicon, SiNx, silicon nitride) and a metallic mirror (Ag). The sensitive area of each chip measures $25 \times 25 \mu\text{m}^2$ for a thickness of 20 nm. The substrate is surrounded by a standard fiber ceramic sleeve allowing connection of a single-mode fiber ferrule.

In order to measure the TES quantum efficiency, its rates are compared to the photon rate seen by a CCD camera. All detectors were connected to the same 1064-nm laser through a 25:25:25 beam splitter preceded by attenuators. Two fiber setups were connected successively to the CCD camera (see Fig. 1). The long bare fiber setup was

Fig. 1 Back-to-back measurement of the ALPS TES quantum efficiency using a well-known PIXIS CCD Camera [4]. The laser signal is focused to the CCD through a 1064-nm fiber collimator followed by a lens

identical to the ones connected to both TESs, while the short setup was an unmodified 1-m fiber with jacket. Switching fibers allowed us to probe for environmental effects and to test the similarity of all the outputs of the beam splitter.

3 Characterization

The silicon-based CCD camera shows a very low-average quantum efficiency of $(1.208 \pm 0.002 \text{ stat} \pm 0.079 \text{ sys}) \%$ for 1066 nm photons [4], while the expected quantum efficiency for the TES is up to 95 % [3]. To optimize the CCD camera's signal-to-noise ratio, 5-min exposure measurements were taken while numerous 1-s timelines (limited by our current DAQ system) were recorded with both TES detectors simultaneously. During the measurements, care has to be taken to avoid photon rates higher than 1 kHz to avoid significant pile-up at the TES [2], which would hinder effective single-photon counting.

Corrections to the beam splitter ratios linked to the non-perfect distribution of the input power were made (28:27:22:23). Overall, a first estimation of 30 % was obtained regarding the ALPS Transition-Edge Sensors quantum efficiency.

4 Optimization

The current measured quantum efficiency of the ALPS TESs is much lower than what could be achieved pointing to different possible issues.

Dust on the chip surface could explain such losses. Indeed, deposits on the substrate surrounding the TES could induce a tilt of the fiber connector or a large free space between the fiber end and the detector surface. It has been shown that a gap in the warm larger than 20 μm will cause a severe decrease in transition-edge sensors quantum efficiency [3]. Such losses could likewise be induced by damages of the antireflective coating. Finally, decrease in the performances of the fiber at very low temperature could cause a variation of the beam splitter characteristics not taken into account currently.

All of these different factors will be investigated in the near future.

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References

1. R. Bähre et al., JINST **8**, T09001 (2013). doi:[10.1088/1748-0221/8/09/T09001](https://doi.org/10.1088/1748-0221/8/09/T09001)
2. J. Dreyling-Eschweiler et al., J. Mod. Opt. **62**, 14 (2015). doi:[10.1080/09500340.2015.1021723](https://doi.org/10.1080/09500340.2015.1021723)
3. A.E. Lita, A.J. Miller, S.W. Nam, Opt. Express **16**, 5 (2008). doi:[10.1364/OE.16.003032](https://doi.org/10.1364/OE.16.003032)
4. J.E. Von Seggern, Constraining weakly interacting slim particles with a massive star and in the laboratory, Dissertation, Fachbereich Physik der Universität Hamburg, 2014, pp. 88–95. http://www3.physnet.uni-hamburg.de/services/fachinfo/___Volltexte/Jan_Eike___von_Seggern/Jan_Eike___von_Seggern.pdf