Characterization of a Transition-Edge Sensor for the ALPS II Experiment

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The ALPS II experiment, Any Light Particle Search II at DESY in Hamburg, will look for light ($m < 10^{-4}$ eV) new fundamental bosons (e.g., axion-like particles, hidden photons and other WISPs) in the next years by the mean of a light-shining-through-the-wall setup. The ALPS II photosensor is a Transition-Edge Sensor (TES) optimized for $\lambda = 1064$ nm photons. The detector is routinely operated at 80 mK, allowing 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% at $\lambda = 1064$ nm as shown in [1]. For 1064 nm photons, the measured background rate is $< 10^{-2}\,\mathrm{sec}^{-1}$ and the intrinsic dark count rate in a dark environment was found to be of $1.0 \cdot 10^{-4}\,\mathrm{sec}^{-1}$ [2]. Latest characterization results are discussed.

1 Single photon detection for ALPS II

The ALPS II experiment will be looking for new fundamental bosons. Such a light-shining-through-the-wall experiment requires a high quantum efficiency low background single-photon detector [3]. A Tungsten Transition-Edge Sensor, which is optimized for low-background high quantum efficiency single photon detection, has been developed by NIST (National Institute of Standards and Technology).

2 Detector setup

2.1 Tungsten Transition-Edge Sensor

TESs are superconductive microcalorimeters measuring the temperature difference ΔT induced by the absorption of a photon. They are operated in a strong negative electro-thermal feedback corresponding to a constant voltage bias.

When a 1064 nm photon is absorbed by the tungsten chip, the sensor temperature raises by 0.1 mK. Heating up of the detector brings it from its superconductive stage to close to its normal resistive stage with an increase of the resistance of $\Delta R \approx 1\Omega$. This leads to a decrease of the current with I $\approx$ 70 nA. TESs are inductively coupled to a SQUID (Superconducting Quantum Interference Device) that converts this current variation in a voltage difference of $\Delta V \approx -50$ mV.

The ALPS II detector module is constituted of two TESs coupled to a SQUID. Both detectors are $25 \times 25\ \mu m^2$ large and 20 nm thick. A ceramic standard mating sleeve towers above each detector, allowing the coupling of a standard single-mode fiber.

2.2 Adiabatic Demagnetization

Transition-Edge Sensors are superconductive detectors. The detector needs to be placed in a bath at $T_{bath} = 80\,\mathrm{mK} \pm 25\,\mu\mathrm{K}$. In order to do so, the TES is placed in an Adiabatic Demagnetization Refrigerator (ADR).

ADR cryostats can reach two low-temperature levels [4]. A temperature baseline of 2.5 K at the colder stages of the cryostat is reached with the help of a compressor using helium and a pulse-tube cooler. The duration of this cool-down procedure is only limited by maintenance works and the necessary modifications of the setup. Within a cool-down, many phases at 80 mK can be reached in two hours through adiabatic demagnetization. Such a recharge lasts approximately 24 hours.

3 TES Characterization

3.1 Pulse shape

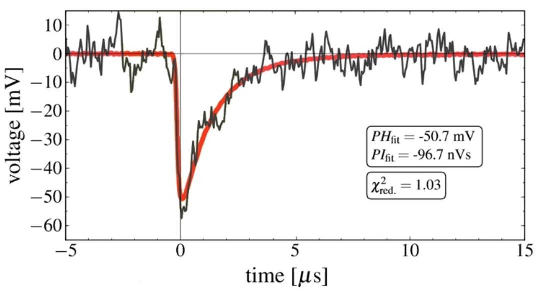

Figure 1: Infrared single-photon pulse shape.

The average pulse shape for 1064 nm photons shows a Peak Height of PH ≈ -50 mV and a Peak Integral of PI ≈ -100 nV (Fig. 1). A mask, corresponding to an average pulse, is fitted to the pulses for different scaling factors a and shift values j towards the trigger point [2].

3.2 Linearity and energy resolution

The linearity of the ALPS II W-TESs was tested by analysing the detector response to different photon energies. Four different lasers were used to that purpose (1064, 645, 532, 405 nm). In Figure 2, the average PH is shown depending on the energy of the photons absorbed by the detector. The sensors are linear in our region of interest (1.17 eV) [2]. The non-linearity at higher energies matches expectations (saturation of the detector). The energy resolution of the detectors for these different wavelengths was measured to be $\Delta E/E < 8\%$ [2].

3.3 Stability

Detection stability over time is essential for the ALPS II experiment where long-term measurements will be performed. Stability during a cool-down as well as between different cool-downs has been checked successfully. The most essential characteristic of the detector is its stability during a recharge-cycle corresponding to the data-taking period. The TES bias current (i.e. TES working point (Fig. 3)) has been measured to be reasonably stable with a maximum gradient $< 1.5\,\mu$A. This variation in the TES bias current corresponds to a variation in the peak height of ΔPH $< 3\%$. Finally, the results have been proven to be operator independent (adjustment method) [2].

4 Summary

Transition-Edge Sensors seem to ideally meet the ALPS II detector challenges. The characterization of the sensors provided by NIST has demonstrated a good detector energy resolution as well as a good stability of the pulse shape over long-term measurements. In addition to this, both detectors have shown a good linearity in the ALPS II region of interest (1.17 eV).

In the near future, optimization of the detector quantum efficiency as well as reduction of the background will be performed.

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References

[1] A. E. Lita, A. J. Miller and S. W. Nam, "Counting near-infrared single-photons with 95% efficiency," Optics express **16**, 5 (2008).

[2] J. Dreyling-Eschweiler *et al.*, "Characterization, 1064 nm photon signals and background events of a tungsten TES detector for the ALPS experiment," J. Mod. Opt. **62**, 14 (2005) [arXiv:1502.07878 [hep-ex]].

[3] R. Bähre *et al.*, "Any light particle search II Technical Design Report," JINST **8**, (2013) [arXiv:1302.5647v2 [hep-ex]].

[4] G. K. White, P. J. Meeson, "Experimental techniques in low-temperature physics," Fourth Edition (2002).

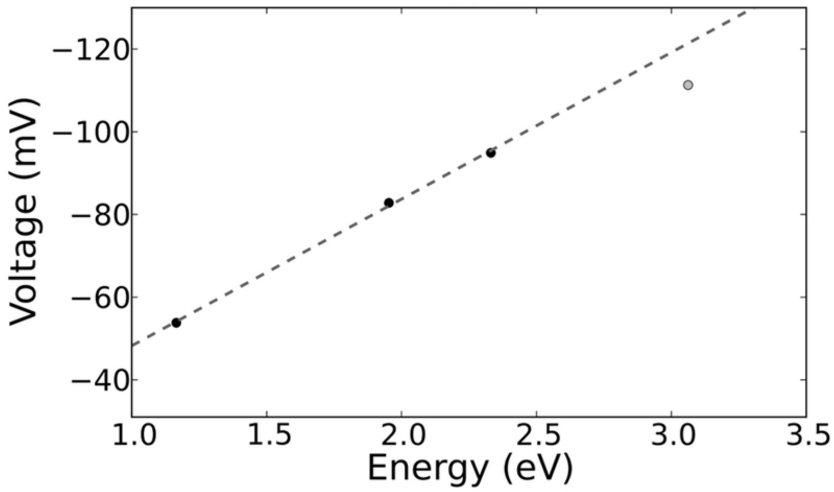

Figure 2: Average pulse height in units of voltage output as a function of photon energy for the TES. The dashed line is a fit to the first three points.

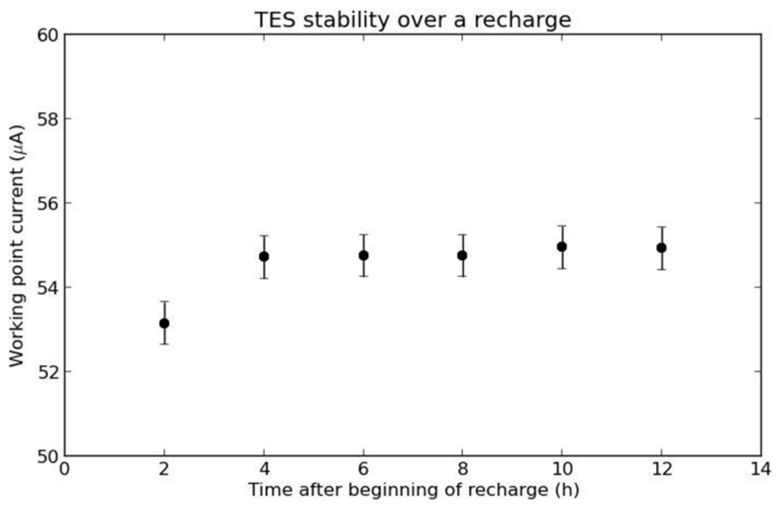

Figure 3: The TES working point current equivalent to $R_0 = 30\% \, R_{normal}$ as a function of time after the beginning of a recharge.