

Ultrafast X-Ray Nanowire Single-Photon Detectors and Their Energy-Dependent Response

Kevin Inderbitzin¹, A. Engel¹, A. Schilling¹, K. Il'in², M. Siegel²

¹Physics Institute, University of Zurich, Winterthurerstr. 190, 8057 Zurich, Switzerland

²Institute for Micro- and Nanoelectronic Systems, Karlsruhe Institute of Technology, Hertzstr. 16, 76187 Karlsruhe, Germany
kevin.inderbitzin@physik.uzh.ch

Abstract

More than a decade before the successful development of superconducting nanowire single-photon detectors (SNSPD) for the optical and near-IR wavelength range [1], serious efforts were undertaken to use this detection principle for the detection of X-ray photons with keV-energies [2]. However, these preliminary X-ray detectors struggled with problems regarding the relaxation back into the superconducting state after photon detection, called latching, making it difficult to operate the devices in a continuous detection mode. Recently, SNSPDs were used in time-of-flight spectrometry of molecules [3, 4]. For this purpose, a SNSPD from 5 nm thin NbN was successfully tested for X-ray detection in a feasibility study [5]. However, the absorptivity of thin NbN films for X-ray photons and therefore the quantum efficiency of the detectors were low.

In order to enhance the absorptivity of the superconducting detector, we fabricated an X-ray superconducting nanowire single-photon detector (X-SNSPD) from 100 nm thick niobium (Fig. 1(a)). The detector geometry was designed for a kinetic inductance large enough to significantly reduce the above mentioned problem with continuous photon detection, and small enough for ultrafast pulse recovery times.

We report on the detection of X-ray photons [6] with keV-energies in continuous mode with an ultrafast pulse recovery time T_P of less than 4 ns (Figs. 1(b) and (c)) and an average pulse rise time of about 190 ps (Fig.1(d)), the latter being limited by our electronics setup. In contrast to optical photon-detection in thin-film SNSPDs, X-ray photon detection was possible even at bias currents smaller than 0.4 percent of the critical current (Fig. 2 inset (a)).

Most remarkably, we observed that the X-SNSPD signal amplitude distribution depends significantly on the acceleration voltage of the photon emitting X-ray tube. Figure 2 shows the corresponding normalized pulse amplitude histograms at different acceleration voltages between 7 kV and 50 kV. Since the detector operates in a single-photon detection mode (Fig. 2 inset (b)) the variation of the signal amplitude distribution can be attributed to the variation of the photon energy spectrum at different X-ray tube settings. This phenomenon, which is new for SNSPDs, is explained by the orders-of-magnitude smaller resistance of the normal conducting domains as compared to the situation in thin-film SNSPDs. For acceleration voltages of the X-ray tube larger than 12.5 kV, we observe distinct preferred signal amplitudes (see arrows in Fig. 2) which we may tentatively ascribe to the main characteristic emission lines of the tungsten target at 8.4 kV and 9.7 kV, for which a minimum excitation energy equal to 10.2 keV or 11.5 keV resp. is necessary. These observations may hint to a certain energy-resolving capability of our niobium X-SNSPD.

Moreover, no dark count events were triggered in over five hours of measurement, even with bias currents very close to the critical current. Our results show that ultrafast dark-count-free X-SNSPDs can be fabricated which can operate in a large spectral range. They could find applications where very high count rates, precise timing, a good signal-to-noise ratio and response in a wide spectral range for photon counting are required, such as experiments with synchrotron X-ray sources, free-electron lasers and hot plasmas (as in nuclear fusion experiments).

In addition, X-SNSPDs from 100 nm thick TaN have been fabricated and characterized, which show an increased X-ray absorptivity and reduced sensitivity for latching compared to the X-SNSPD from Nb.

References

- [1] G. N. Gol'tsman, O. Okunev, G. Chulkova, A. Lipatov, A. Semenov, K. Smirnov, B. Voronov, A. Dzardanov, C. Williams, and R. Sobolewski, *Appl. Phys. Lett.*, **79** (2001) 705
- [2] A. Gabutti, R. G. Wagner, K. E. Gray, R. T. Kampwirth, and R. H. Ono, *Nucl. Instrum. Methods A*, **278** (1989) 425.
- [3] K. Suzuki, K. Suzuki, S. Miki, Z. Wang, Y. Kobayashi, S. Shiki, and M. Ohkubo, *J. Low Temp. Phys.*, **151** (2008) 766.
- [4] N. Zen, A. Casaburi, S. Shiki, K. Suzuki, M. Ejrnaes, R. Cristiano, and M. Ohkubo, *Appl. Phys. Letters*, **95** (2009) 172508.

- [5] D. Perez de Lara, M. Ejrnaes, A. Casaburi, M. Lisitskiy, R. Cristiano, S. Pagano, A. Gaggero, R. Leoni, G. Golt'sman, and B. Voronov, *J. Low Temp. Phys.*, **151** (2008) 771.
 [6] K. Inderbitzin, A. Engel, A. Schilling, K. Il'in, and M. Siegel, to be published

Figures

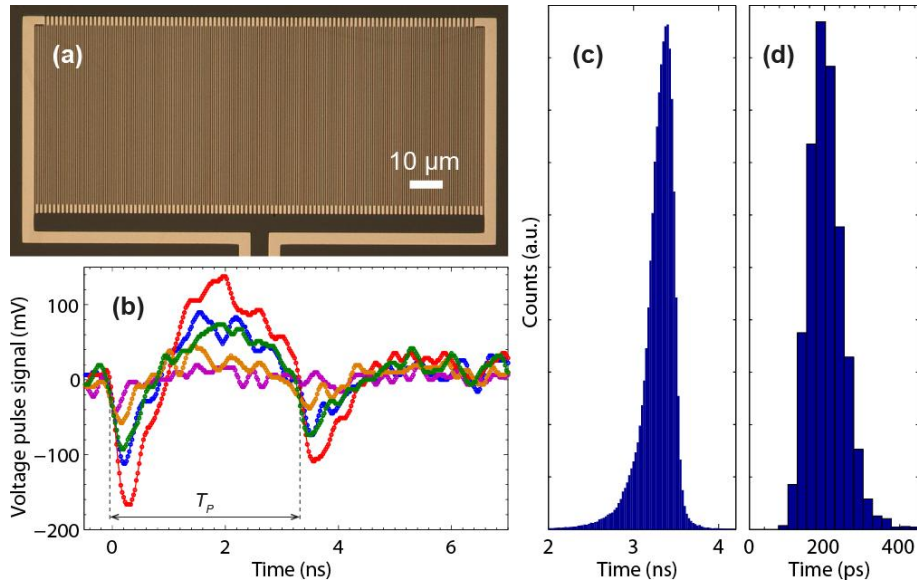


Fig. 1: (a) Optical image of examined X-SNSPD from 100 nm thick niobium. (b) Typical voltage pulses after X-ray photon absorption, with definition of the pulse length T_P shown schematically. (c) Pulse length T_P histogram. (d) Pulse rise time histogram (time spans between 15 and 85 percent of pulse amplitude). For (b)-(d) the X-SNSPD was irradiated by the X-ray tube with an acceleration voltage of 49.9 kV.

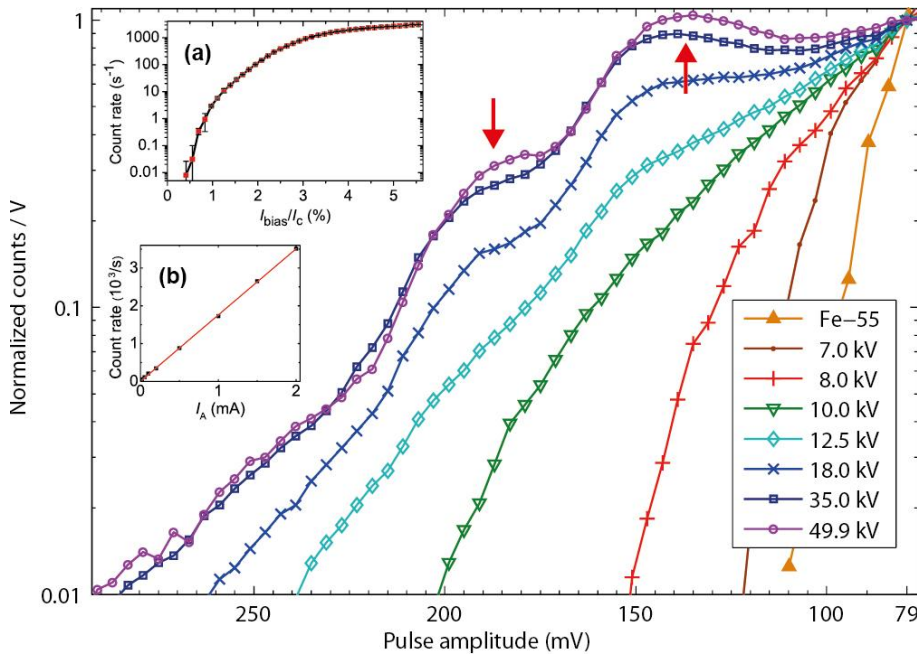


Fig. 2: Histograms of signal amplitudes from photons emitted by the X-ray tube at different tube acceleration voltages (indicated in the legend) and from photons emitted by a radioactive Fe-55 source, which mainly emits at 5.9 keV. The tube acceleration voltage determines the maximum energy of the emitted photons. The histograms use a bin size of 4 mV (5.2 mV for the Fe-55 data respectively) and are normalized at -79 mV, which lies below the noise level. The two arrows indicate preferred signal amplitudes which may tentatively be ascribed to the main characteristic emission lines of the tungsten target at 8.4 kV and 9.7 kV. **Inset (a)** shows a plot of the count rate as a function of the reduced bias current at an acceleration voltage of 49.9 kV. **Inset (b)** shows that the X-SNSPD photon count rate is proportional to the photon flux, which is varied by the X-ray tube anode current.