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Laser Induced Relaxation Oscillations in Superconducting Nanobridge Single Photon Detectors

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Abstract: We present the first observations of laser synchronised relaxation oscillations in superconducting nanowire single photon detectors. Understanding the thermal feedback behind these oscillations aids the development of photon number resolving and higher count rate detectors.

1. Introduction

Superconducting Nanowire Single Photon Detectors (SNSPD's) are a successful technology for applications in quantum optics and can enable optical quantum computation. A limitation of current SNSPD's is the lack of intrinsic, single-nanowire, multiphoton resolution. Recent work demonstrates the capability of a single wire SNSPD to resolve photon numbers [1–3]. In this work we present the first observations of laser induced relaxation oscillations in nanoscale bridges of 70 nm to 150 nm width. We analyze these synchronized oscillations in terms of electro-thermal feedback mechanisms in SNSPD's. Understanding the underlying physics of these feedback mechanisms aids achieving better photon number resolution and faster count rates in the next generation of SNSPD's.

2. Methods

The nanobridge SNSPD's in this study are fabricated out of 9 nm thin film NbTiN with $T_c = 8.7\,\mathrm{K}$ and are placed on a Si substrate with a thermal SiO_2 layer. The detectors consist of a nanowire constricted to a section of equal length and width of 70 nm, 100 nm, 120 nm and 150 nm and are connected in series with a wide wire with $\sim 700\,\mathrm{nH}$ inductance to prevent latching. Figure 1 shows the measured I-V curve for a 120 nm-wide nanobridge SNSPD at a temperature of 6 K. A voltage source is used in combination with 10 kΩ and 50 Ω resistors to create a quasi current bias (see inset). The detector is illuminated by a pulsed picosecond laser with a $\sim 20\,\mathrm{MHz}$ repetition rate. Using free-space optical access the laser is focused on the detector and the average power is varied from 0.5 nW to 50 μW to explore the response of the detector using the method of detector tomography [4].

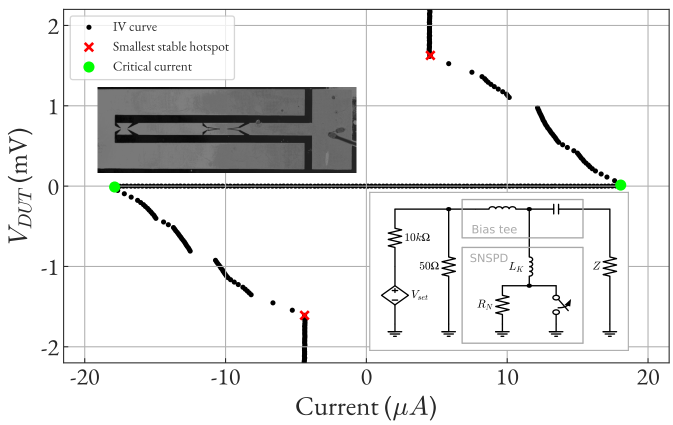

Fig. 1. Measured IV of a $120 \times 120\,\mathrm{nm}^2$ NbTiN nanobridge SNSPD at $T = 6\,\mathrm{K}$. The critical current ($\sim 18\,\mu\mathrm{A}$) is indicated by a green dot. The stable hotspot regime, indicated by a red dot, is achieved at larger voltages. Relaxation oscillations are observed for $0\,\mathrm{mV} < |V_{DUT}| < 1.5\,\mathrm{mV}$. Inset is an optical image of the detector (top left) and the electrical circuit to bias the detector (bottom right).

3. Results

It is well-known that the detection efficiency of SNSPD's increases as a function of bias current through the wire. In addition, we observe both regular relaxation oscillations and novel laser-driven induced relaxation oscillations as a function of the bias voltage. These laser driven oscillations occur at high bias currents, well after the optical response reaches saturation. The frequency of these oscillations increases with bias voltage and optical power. Interestingly, the relaxation oscillations phase-lock to the laser pulses and the oscillation frequency becomes an integer multiple (up to $4\times$) of the $\sim 20\,\mathrm{MHz}$ laser repetition rate, as shown in figure 2 (bottom). Data are shown together with an autocorrelation of the laser-driven oscillations in 2 (top). The autocorrelation clearly demonstrates the phase-locking of the relaxation oscillations. This mechanism differs from the free standing relaxation oscillations where the oscillation frequency varies continuously [5].

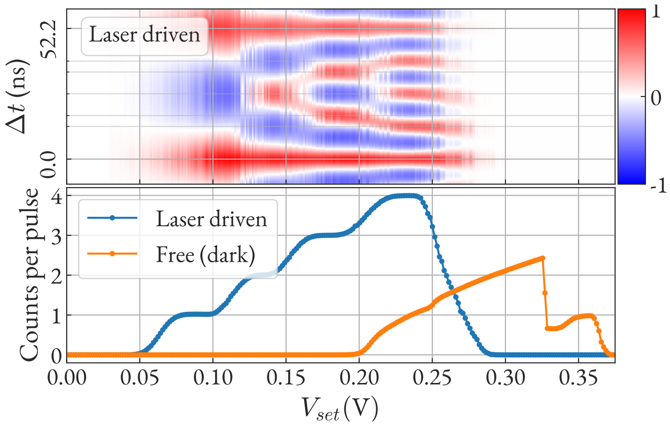

Fig. 2. Laser driven relaxation oscillations. (top) Auto correlation traces of the time traces for the laser induced relaxation oscillations. (bottom) Count rate of the detector as a function of bias voltage applied to the circuit. In blue the count rate with pulsed light illumination is shown, in orange the free relaxation oscillations.

4. Discussion

In this work we show the first observations of laser induced relaxation oscillations in superconducting nanobridge single photon detectors. These laser induced relaxation oscillations occur beyond the regime where the single-photon count-rate saturates. The 1/e electronic reset time of these detectors is $\sim 15\,\mathrm{ns}$ regulated by the $\sim 700\,\mathrm{nH}$ inductance, making the reset rate ($\sim 70\,\mathrm{MHz}$) comparable to the laser repetition rate. In this regime the assumption that two consecutive detection events are independent is no longer valid, which leads to a new regime of relaxation oscillations. The maximum count rate of the relaxation oscillation is limited by both the electrical circuit and the light intensity. More narrow nanobridges have a stronger tendency to show laser induced relaxation oscillations. Our observations indicate that energy transfer to the substrate plays an important role in the novel-phenomenon of light induced relaxation oscillations. We will present a model to explain these oscillations and explore the physical limits to photon number resolution and maximum count rate.

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