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Thermal avalanche in superconducting nanowire single photon detectors fabricated from WSi/αSi multilayers

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Over the past decade, superconducting nanowire single-photon detectors (SNSPDs) have become promising alternatives to conventional semiconductor avalanche photodiodes due to their high timing resolution and low dark count rates [1]. Recently, we demonstrated record-high system detection efficiencies (SDE) using SNSPDs based on an amorphous superconductor, WSi [2]. However, the low carrier density in this material results in low switching currents (the current at which the critical current density is exceeded) relative to NbN nanowires [3]. As a result, the signal-to-noise ratio is degraded which degrades the timing resolution (jitter).

To increase the signal-to-noise ratio, a scheme in which multiple nanowires are connected in parallel can be used. Such devices have been called superconducting nanowire avalanche photodetectors (SNAPs) [4, 5]. We showed in previous work that it is possible to stack two nanowire meanders on top of each other that are electrically connected in parallel, and separated by a 75 nm-thick spacer [6]. However, the jitter of these detectors was worse than that of a typical single-pixel WSi SNSPD due to the large inductance added in series (10 times the inductance of a single pixel [4]).

Here we present a simplified stacking scheme in which multiple layers of WSi superconductor are separated by thin amorphous silicon (αSi) spacer layers. The fabrication is simplified relative to our previous work in that all layers are deposited in the same step. One electron beam lithography and etching step defines the nanowires into all layers simultaneously. This fabrication approach is readily scalable to three or more layers.

Unlike traditional SNAP designs, we show that the avalanche mechanism in WSi / αSi multilayers is thermal instead of electrical. The "hotspot" produced by the absorption of a photon and Joule heating results in the production of athermal phonons that can move through the electrically insulating αSi layer. The energy from these phonons is large enough to create a hotspot in the adjacent nanowire, so that both nanowires switch to the normal state for a single photon absorption event. To prove this, we fabricated two single nanowires separated by an 8 nm-thick layer of αSi. The nanowires cross at right angles, with one nanowire overlapping the other. Each nanowire could be independently current-biased. We observed strong correlations between electrical pulses produced by the two nanowires when both were biased, suggesting thermal crosstalk as the source of correlations.

SNSPDs were fabricated from a WSi / αSi stack consisting of 4 nm WSi / 4 nm αSi / 4 nm WSi / 2 nm αSi. We show that the switching current of this detector increases by a factor of 2 relative to a single-layer device, without the need for additional inductance. This is in contrast to the traditional SNAP design, which requires adding a large inductor in series with the detector [4]. Thus, the signal-to-noise ratio of the output pulse is increased without increasing the rise time of the pulse (proportional to the kinetic inductance). The result is a significant decrease in jitter. In addition to the reduction in jitter, absorption is increased by a factor of two, which simplifies the fabrication of an optical cavity around the device to enhance absorption.

Although SNSPDs based on amorphous superconductors have demonstrated record-high efficiencies [2], they have suffered from low switching currents and large jitter compared to NbN-based SNSPDs. The thermal SNAP may be a solution to the problem of low switching currents and high jitter in SNSPDs based on amorphous materials, allowing high-efficiency SNSPDs to be fabricated with jitter comparable to NbN SNSPDs.

[1] G. N. Gol'tsman, et. al., Appl. Phys. Lett. 79, 705 (2001).
[2] F. Marsili, et. al., Nat. Photonics 7, 210 (2013).
[3] Natarajan, et. al., Supercond. Sci. Technol. 25, 063001 (2012).
[4] F. Marsili, et. al., Nano Letters 11, 2048 (2011).
[5] M. Ejrnaes, et. al., Appl. Phys. Lett. 91, 262509 (2007).
[6] V. B. Verma, et. al., Appl. Phys. Lett. 101, 251114 (2012).