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## Viewpoint

# Prospects for faster, higher-temperature superconducting nanowire single-photon detectors

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This is a viewpoint on the letter by M Erjnaes *et al* (2017 *Supercond. Sci. Technol.* **30** 12LT02).

Superconducting nanowire single-photon detectors (SNPSDs) have demonstrated single-photon detection in the visible and near-infrared with near unity quantum efficiency, ∼ns reset times, very low dark count rates, and ∼10 ps timing resolution. As a result, they have become attractive for some of the most demanding single-photon applications such as quantum cryptography, deep space communication, and single-molecule fluorescence [1]. The first SNSPDs were made from niobium nitride (NbN) [2, 3]. Subsequent work has explored a variety of other low-$T_c$ materials, including NbTiN [4], NbSi [5], WSi [6], MoGe [7], and MoSi [8].

High-$T_c$ materials have also been explored, with limited success to date. A higher critical temperature offers two important advantages: a higher operating temperature, which makes the devices more attractive for many applications; and the possibility of a significantly faster count rate. In SNSPDs, the reset time is set by the inductive time constant, where the inductance is typically dominated by the kinetic inductance of the nanowire. A faster device can be achieved by reducing this inductance (e.g. by reducing the nanowire length), but if the inductive time constant is no longer slower than the time it takes the photon-induced resistive hotspot to cool, then the device will no longer self-reset following photon detection, instead remaining in a resistive state—a phenomenon known as latching. The hotspot cooling time is typically limited by the electron–phonon inelastic scattering time, although in some cases the phonon escape time becomes the limiting factor. As the electron–phonon time depends strongly on temperature, a higher $T_c$ can result in a significantly faster cooling time and hence a faster non-latching device.

Visible single-photon detection has been demonstrated in $MgB_2$ nanowires with a $T_c$ as high as 31 K (compared to 39 K in the bulk material) and an operating temperature as high as 11 K [9, 10]. The response time of these devices was similar to NbN SNPSDs, ∼ns. In practice, many of the attractive properties of the bulk material—particularly the $T_c$, transition width $\Delta T_c$, and critical current density—are degraded by the process of producing an ultra-thin film ($\lesssim$10 nm) and patterning this film into an ultra-narrow wire ($\lesssim$100 nm). Realizing an $MgB_2$ SNSPD with more optimal properties remains a work in progress.

The high-$T_c$ cuprates offer a potentially attractive platform for SNSPDs with even higher operating temperatures, but to date a cuprate SNSPD has not been realized. Previous studies of YBCO and LaSrCuO nanowires have shown a photoresponse but not single-photon sensitivity [11, 12]. In a recent letter, Ejrnaes *et al* report the observation of dark counts in a YBCO nanowire [13], a significant step toward realizing single-photon detection. A dark count produces an output identical to photon detection but is caused by another perturbation, typically a thermal fluctuation. The observation of dark counts indicates that the device should be single-photon sensitive for some as-yet-undetermined photon energy.

The YBCO device consists of a 10 nm thick, 65 nm wide, and 80 nm long nanowire patterned via argon ion milling through a hard carbon mask. Below 10 K, the current–voltage curves exhibit hysteretic behavior, a hallmark of the unstable electrothermal feedback necessary for proper SNSPD operation. In this temperature range, dark counts are observed. The bias-current-dependence of the dark counts is consistent with thermal activation. A large inductor was placed in series with the device to prevent latching. The ultra-thin films used for these devices exhibit a normal-state resistivity about a factor of two larger than thicker films, and patterning the nanowire lowers the $T_c$ by about 5 K from the unpatterned film.

Realizing a practical YBCO SNSPD likely requires further improvements in the film growth and patterning processes. In particular, one wants a long nanowire with a high critical temperature, narrow transition width, and high critical current density combined with hysteretic current–voltage behavior that persists up to temperatures that are a significant fraction of $T_c$. Given the higher operating temperature and correspondingly fast electron–phonon time in such a device, the cooling rate of the resistive hotspot should be limited by the phonon escape time, which is about 0.5 ns for 10 nm thick YBCO on sapphire [14]. Thus the choice of substrate and the interface between the nanowire and the substrate will likely be critical for determining the maximum possible count rate.

The development of high-$T_c$ SNSPDs would benefit from accurate electrothermal modeling. Such modeling, which has been implemented by several groups for NbN SNSPDs [15–17], should be able to estimate the nanowire geometry and other physical properties needed to achieve single-photon sensitivity at a particular wavelength for a particular material. It should also be able to provide guidance on the material properties needed to exhibit hysteretic current–voltage behavior.

An optimized SNSPD with an operating temperature of several tens of kelvin and a sub-ns response time would certainly expand the practical application of these detectors. While challenges remain, the work by Ejrnaes *et al* represents an important step toward the realization of such a device.

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