Superconducting nanowire single-photon detectors (SNSPDs) for microscopy

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Abstract

Superconducting nanowire single-photon detectors (SNSPDs) are a mature technology that provide high quantum efficiency for single-photon detection combined with sub-20 picosecond time resolution and high dynamic range, in a wide variety of wavelengths, from visible to NIR. Therefore, there are a wide range of scientific and technological applications that are benefiting from SNSPDs, such as quantum optics, space communications and, more recently, optical microscopy.

Commercially available SNSPDs have been used as detectors for confocal microscopy in the short-wave infrared (SWIR) region of the spectrum [1,2], where light propagation in biological tissue has a minimum absorption and thus the penetration depth for imaging is maximized. In such a configuration, we were able to image the brain of live mouse with a simple one-photon confocal configuration achieving a penetration depth >1.3mm, comparable with two-photon microscopy [1]. Furthermore, we showed that it is possible to image the brain through the skull, avoiding the need for surgery and still resolve biologically relevant structures as deep as 500 µm [2].

We present a newly developed free-space-coupled SNSPD system equipped with an array of 6x6 SNSPDs. The system was coupled to our home-made SWIR confocal microscope to create an Image Scanning Microscopy (ISM) setup capable to detect light in the wavelength range >1050nm. Figure 1 presents an overview of the system. Figure 1 (a) depicts the SNSPD system (including the closed-cycle cryostat needed to reach the superconducting state of the detectors) mounted on an optical table with optical access from the bottom side. Light goes in through optical windows and gets focused on the detectors by a lens located inside the cryostat. Figure 1 (b) depicts a scheme of the SWIR microscope with the two imaging modes: confocal, using a single-mode-fibre-coupled SNSPD, and the free-space 6x6 array of SNSPDs that allows for ISM. The excitation source is a laser diode at 1064nm and the detection channels available range from 1100nm to 1900nm. Figure 1 (c) depicts a confocal image of a star-patterned sample taken with the microscope summing all the pixels in the array (left) and the same image reordered with the individual pixels of the array (right). We show the raw data directly recorded and no post processing was done. The use of an array enables an increase in resolution compared to single-pixel confocal [3] and an increased dynamic range, allowing the detection of extremely bright emitters and single-photons on the same sensor. Moreover, since we access the SNSPDs detection events individually, we could employ a time tagger to perform an ISM in combination with fluorescence lifetime, as it was done before with SPAD arrays [3].

SNSPDs have shown to be useful for different state-of-the-art photonics application, in particular for microscopy of biological tissues. Here, we use a newly developed SNSPD sensor in combination with a SWIR microscope, that will allow to achieve deep tissue imaging into biological samples with better resolution than a standard SWIR confocal.

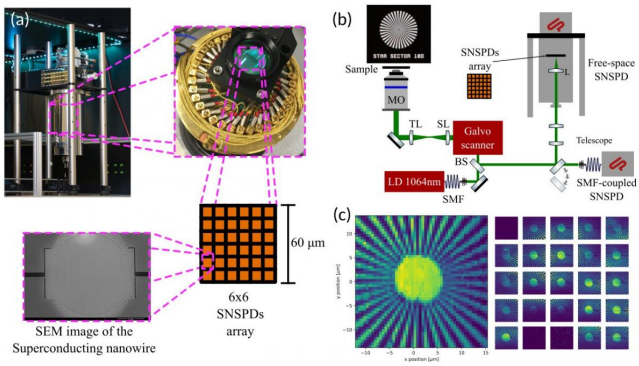

Figure 1: (a) SNSPD free-space system, featuring the complete system (top left), the focusing lens inside the cryostat (top right), the 6x6 array (bottom right) and a SEM image of a single SNSPD. (b) SWIR confocal microscope with an array of SNSPDs for ISM and a fiber-coupled SNSPD for standard confocal imaging. (c) (left) confocal image of a target sample using the complete SNSPD array. (right) individual pixel images recorder by each pixel in the array.

References

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