



Viewpoint

A switch made from a nanowire and its application in a superconducting strip ion detector

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This is a viewpoint on the letter by A Casaburi *et al* (2018 *Supercond. Sci. Technol.* 31 06LT01).

Superconducting nanowires or strips, the name depending on the width of the wire, are used for making sensitive detectors [1–3]. One kind of these are superconducting strip ion detectors (SSIDs), which have promising features in time-of-flight mass spectrometry [2]. The width of the strip is typically $1\ \mu\text{m}$. To cover a large detection area, a long single strip is shaped into a square. The length of the wire l is $l = A/(w + s)$, where A is the size of the shaped area, w is the width of the strip, and s is the spacing between adjacent strips. The larger the detector area is, the longer the strip. Since the strip is both narrow and thin, compared to the London penetration depth, the kinetic inductance of the strip is much higher than the Faraday inductance by about one to two orders of magnitude [4]. Such high inductance limits the reset time of the biasing current, and thus determines the speed of SSIDs. The kinetic inductance limited reset time also occurs in detectors that are made from ultra thin nanowires, e.g. superconducting nanowire single photon detectors (SNSPDs) [5].

To reduce the inductance of a superconducting wire-based detector, a natural solution is to reassemble the wires in a parallel structure instead of connecting them in series [6, 7]. To cover the same detection area, for a parallel SSID with N wires, the total inductance is reduced to L_s/N^2 , where L_s is the total inductance of all the wires. It sounds like a great idea with little work. However, Casaburi *et al* found that current did not distribute evenly among the strips and the physics behind the non-uniform distribution was not trivial [8, 9]. With a neat and cryogenic microscope setup, the researchers measured the current distribution, which had a parabolic shape: the center strips had the lowest currents while the outermost strips had the highest currents. By applying the London phenomenological theory, they developed a model that nicely fitted the experimental observation.

The current distribution became more complex when detection dynamics were taken into account. When one strip fired, a hotspot was generated and then grew. The increase in resistance let the current through the fired strip be ejected to other unfired strips as well as the output load. After the strip returned back to a superconducting state, the bias source started to charge the entire device. As Casaburi *et al* observed in their previous work, the final currents through the strips did not return back to the initial levels. Instead, they stayed at different levels depending on the firing location: the wire that fired had the minimum current [9]. The authors explained this phenomenon with a London model and discussed that there appears to have been a vortex crossing of the fired strip following by a detection event.



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The parallel structure gives rise to a lot of interesting physics. From an electrical engineering perspective, the non-uniform current and dynamics of the vortex crossing are disastrous, as it is getting hard to find an optimal layout of an SSID and figure out a biasing current to reach the best detector performance. Recently, Casaburi *et al* demonstrated their solution. They inserted a short superconducting nanowire, which they referred to as an integrated Joule switch, into each strip [10]. As the switch had a lower critical superconducting current, it could be switched to a normal state by applying a proper biasing. The switched superconducting nanowire functioned as a resistor. In this configuration, every strip was connected in serial with a resistor before paralleling. Thus, the biasing current through each strip was governed by Ohm's law. These resistors also destroyed superconducting loops and prevented flux from being trapped. Compared to the conventional parallel SSIDs, the researchers found the current was distributed much more uniformly and such uniform distribution was not affected by a prior detection event.

Casaburi *et al* gave a design for parallel SSIDs to control the biasing current. In the future, it would be exciting to have a super-large SSID with a high performance in areas such as efficiency and speed, as good as the state-of-the-art numbers recorded from smaller ones. Their work also implies that through a good on-chip circuit design, even just by adding a few passive components, the enhancement of detector performance could be spectacular [7, 11–13]. It is noteworthy that superconducting nanowires are being used for making electronics. For example, the nanowire cryotrons invented by McCaughan and Berggren can be thought of as a gate-controlled thermal switch [14]. Zhao *et al* demonstrated a superconducting nanowire memory with multiple integrated nanowire cryotrons [15]. With integration with superconducting electronic devices, superconducting detectors could be upgraded to a sophisticated on-chip electronic system to gain better performance and broaden their applications.

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