The yTron: A nanoscale superconducting 3-terminal device for inline readout of superconducting currents

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The yTron is a nanoscale three-terminal superconducting device which is capable of sensing superconducting currents by kinetic coupling instead of magnetic coupling. This kinetic coupling allows the yTron to sense currents inline, without requiring a magnetic pickup loop. The device is fabricated from a single contiguous layer of superconducting niobium nitride (NbN) thin film which has been patterned into a nanowire "Y" shape. The yTron channel and the gate nanowires form the upper arms of the Y, merging together at a sharp intersection to form a source terminal.

The yTron can be used as an inline current sensor for superconducting currents, because the gate current modulates the switching current of the channel. As a result, by measuring the switching current of the channel (e.g. by current biasing until vortices flow or a hotspot forms in the channel), we were able to infer the magnitude of current flowing into the gate. Effectively, the yTron acts as a three-terminal controllable weak-link: the magnitude of current flowing into the gate terminal controls the passage of flux across the channel terminal. At no point during this process is the current in the gate modified; the vortex flow (or hotspot) is isolated in the channel nanowire, leaving the current flowing through the gate undisturbed. This allows nondestructive readout of superconducting loop currents, which previously was only possible through magnetic coupling.

Modulation of the yTron channel switching current occurs because adding or removing current from the gate alters the current crowding seen by the channel. Components of the gate current which are tangential to the intersection boundary (and thus produce current crowding) oppose those of the channel currents, resulting in reduced current crowding at the intersection. In this way, current added to the gate diminishes current crowding in the channel, and as a result increases the channel switching current.

We have fabricated and characterized yTron devices with different dimensions, and found that the switching current dependence of the channel was highly linear versus the gate current, with a slope that is dependent on the ratio of widths of the gate and channel. Additionally, we verified the ability of the yTron to sense inline superconducting currents without disturbing them. We were able to use the yTron to nondestructively read out the number of discrete fluxons (n) trapped in a superconducting loop. We successfully resolved the adjacent fluxon states (n, n+1, etc) of the loop, and were able to read out those states several thousand times consecutively without changing the value of n.

We expect the yTron will find application as an inline current sensor for devices such as transition edge sensors and superconducting nanowire single photon detectors (SNSPD). In these devices, the yTron may be used to produce large (~10 mV) ancillary outputs for multiplexing or time resolution purposes, without otherwise disturbing the primary readout method. Additionally, as a three-terminal controllable weak link, the yTron can serve as a logic or memory element with which to process and record detection events. Monolithic integration of the yTron with an SNSPD is feasible based on our previous work with the nanocryoton (nTron) which has similar fabrication to the yTron. With the nTron, we were able to demonstrate a complete set of AND/OR/NOT/COPY nTron-based logic gates, as well as integrate an nTron amplifier with a SNSPD in a monolithic fashion. The nTron amplifier was able to amplify the SNSPD signal by a factor of 2.9, as well as reduce the measured jitter of the detector from 41 ps to 23.8 ps.