Large scale integrated superconducting Josephson circuits fabricated with focused helium ion irradiation.

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We have fabricated a variety of high-transition temperature superconducting (HTS) Josephson devices with properties that exceed prior-art devices using a focused helium ion beam (FHIB). These FHIB Josephson junctions have exceptional qualities such as resistance greater than 1k ohms as well as superconducting quantum interference devices with voltage close to 1 mV. These high figures of merit make HTS devices appealing for many applications. Unfortunately, these demonstrations are small scale devices with few junctions contained in small 100 micron areas due to the field of view of the FHIB at high resolution. To bring this technology to the next level, innovations are needed for large area patterning such as those implemented in commercial electron beam lithography equipment. We present our efforts in bringing this to fruition using our Orion plus microscope equipped with a Raith ELPHY pattern generator system. We developed an automated direct-write Josephson junction process where large-scale areas are broken into smaller write fields that are compatible with the field of view of the FHIB. The smaller areas are individually written and stitched together. Since the FHIB is not equipped with a laser interferometer stage, it is necessary to account for stage backlash and other sources of stitching error using auto-alignment marks in the circuit design. Using the Raith ELPHY pattern generator we maintain a small field of view for high resolution patterning and control the stage to stitch the device with errors less than a few micrometers per movement. Additionally, while setting up the coordinate system to match the design and the patterned device, a focal plan is fitted in the coordinate system to keep the beam in focus even after long stage movements. This further reduces the action needed by a human operator. To test the automation process, we designed a large area wide-bandwidth, high-dynamic range sensor which consists of a large number of long Josephson junctions in an array. The array, typically several millimeters long, is much larger than common lithography write fields (typically a hundred micrometers) making the fabrication process excessively long and tedious. The signal voltage output scales with the number of junctions contained in the series array which is an important metric for determining the device performance. Previous designs were limited to a few hundred junctions with output voltage of less than 5 mV. By automating the process, we are now capable of making arrays with over 2600 junctions in series with voltage output over 100 mV!

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