MBE growth of parallel hybrid semiconductor-superconductor nanowires for quantum devices

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Hybrid superconductor-semiconductor materials are attractive for research on several types of gate-tunable quantum devices, such as superconducting qubits [1], Andreev qubits, and cryogenic switches. They have also played an important role in fundamental research on bound states in topological superconductors and quantum dots, where superconductor-semiconductor nanowires have been established as an essential platform [2]. Up to now, these platforms have been based on individual nanowires. However, coupling multiple parallel nanowires could open new avenues. Pairs of parallel nanowires match theoretical proposals for quantum devices, such as Cooper pair splitters and Andreev bound state molecules [3,4].

We present our results on the fabrication of multiple (5-10) parallel hybrid nanowires (Figure 1a). The synthesis (Figure 1b) is based on arrays of closely spaced catalyst particles positioned by electron beam lithography, vapor-liquid-solid growth of vertical InAs nanowires by molecular beam epitaxy (1), vapor-solid radius overgrowth (2) and in-situ deposition of superconducting shells on the coupled wires (3). Our study shows that the parallel wires grow aligned with a yield depending on the distance between adjacent catalyst particles. The yield decreases with decreasing pitch (Figure 2a) and we ascribe this to the merging of Au droplets prior to growth. We will discuss the morphology, structural and electrical properties of the nanowire arrays.

Furthermore, by etching away part of the in-situ deposited Aluminum one can form Josephson junctions, a key element in superconducting circuits (Figure 2b). We show that the supercurrent in the parallel wires is an order of magnitude higher than for a single nanowire device. By embedding the parallel wires in a microwave resonator, we fabricate a Josephson parametric amplifier (JPA). This type of ultra-low-noise amplifier requires a large critical current and has been made before using metal tunnel junctions, graphene [5] and planar semiconductors [6]. We demonstrate the first nanowire-based JPA and show the gate-voltage tunability enabled by this new semiconducting platform.

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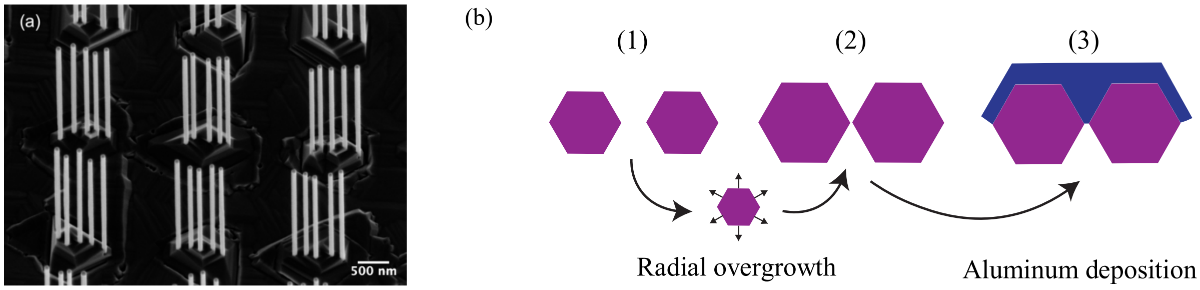

Figure 1: (a) Arrays of InAs nanowires grown by MBE. (b) Schematic representing the three steps growth process for two parallel InAs nanowires (purple, top view) with in situ Aluminum (blue).

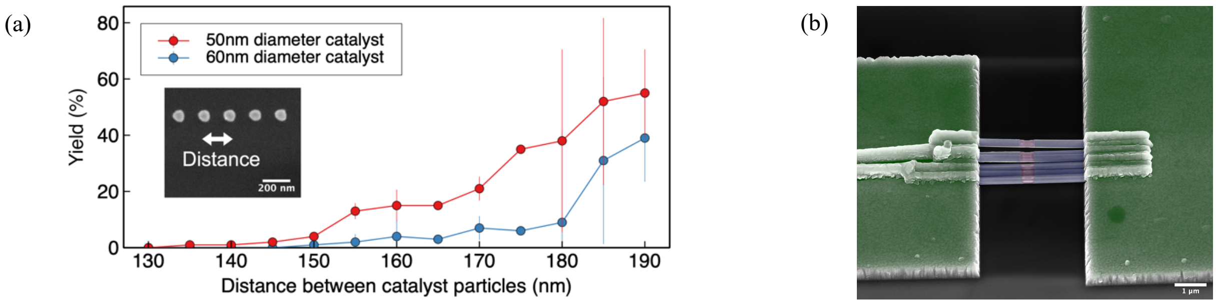

Figure 2: (a) Yield (percentage of successfully grown parallels arrays) with respect to the distance between the catalyst particles in an array before growth for two catalyst diameters (50nm and 60nm). Inset : scanning electron micrograph of gold catalyst particles before growth. White arrow shows the distance between two catalyst particles. (b) Scanning electron micrograph of parallel InAs nanowires (InAs: purple ; in situ Aluminum: blue) Josephson junction contacted with Ti/Al electrodes (green) to perform electronic transport measurements.