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Size Dependent Breakdown of Superconductivity in Ultra-Narrow Nanowires

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Below a certain temperature T_c (typically cryogenic) some materials lose their electric resistance R entering a superconducting state. Following the general trend towards a large scale integration of greater number of electronic components it is desirable to use superconducting elements in order to minimize heat dissipation. It is expected that the basic property of a superconductor, i.e. dissipationless electric current, will be preserved at reduced scales required by modern nanoelectronics. Unfortunately, there are indications that for a certain critical size limit of the order of $\sim$ 10 nm below which a 'superconducting' nanowire is no longer a superconductor in a sense that it acquires a finite resistance even at temperatures close to absolute zero. We developed a method of non-destructive reduction of a nanostructure dimension(s) by low-energy Ar^+ ion sputtering. The method enables study of a purely size phenomena between the sputtering sessions: *same* sample with progressively reduced characteristic dimension. We were able to trace the evolution of the shape of superconducting transition R(T) an aluminum nanowire with original effective diameter $\sim$ 70 nm down $\sim$ 8 nm. Below $\sim$ 15 nm the initially abrupt R(T) dependence suddenly broadens. With further reduction of the wire cross section finite resistance is observed down to temperatures much below the initial superconducting transition. We associate the observed phenomena with the quantum phase slippage process: destruction of superconductivity in quasi-1D channels due to quantum fluctuations of the order parameter. The effect should have a universal validity setting a fundamental size limit for utilization of superconducting elements as building blocks of nanoelectronics circuits.