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Nanoscale semiconductor devices fabricated by atomic force microscope lithography

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Abstract

The continuous shrinking of device dimensions in commercial integrated circuits is a strong motivation for dealing with non-classical transport phenomena. These arise if the lateral dimension becomes comparable with characteristic lengths such as the mean free path or the Fermi wavelength of the charge carriers. Observing non-classical phenomena such as ballistic transport or quantum interference requires a nanolithography process suitable for fabricating semiconductor structures of the order of, or even less than, 100 nm lateral size. The aim of the present lecture is to demonstrate that the atomic force microscope (AFM) is a powerful, versatile lithography tool. In particular, dynamically ploughing an ultrathin resist layer with the vibrating tip of a tapping-mode AFM enables the creation of a complex polygonal line pattern which subsequently is transferred into a GaAs/AlGaAs heterostructure by low-damage wet-chemical etching. Resulting grooves as narrow as 40 nm (>4 nm deep) or up to 55 nm deep (120 nm wide) are achieved which is superior to AFM patterning by direct machining or local anodic oxidation. Even an areal pattern can be realized from a short-period line grating if a stopping layer is used for pattern transfer by selective etching. The AFM nanolithography is applied to fabricate nanoscale devices from a modulation-doped GaAs/AlGaAs heterostructure. Narrow grooves are employed to create local barriers in a high-mobility two-dimensional electron gas (2DEG) forming a ballistic constriction. At T = 4.2 K the occurrence of quantized conductance proves purely ballistic electron transport while the subband separations up to 20 meV indicate a narrow confining potential. Compensating-layer GaAs/AlGaAs heterostructures where the 2DEG is initially depleted due to an additional p-type doped capping layer are used to simultaneously define wide leads and quantum wires or quantum rings from areal and line patterns. Also, these structures delineate signatures of ballistic transport at T = 4.2 K. Magnetic Aharonov-Bohm oscillations with periods up to 0.5 T demonstrate a present lithography limit of only 110 nm loop diameter.