Focused Ion Beam Direct Patterning of Suspended Two-Dimensional Electron Gases

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Focused Ion Beam (FIB) technology was introduced in the late 1970's[1]. It has since been widely used, among other applications, for direct and resist-free patterning of semiconductor devices at the nanoscale, with very high resolution capabilities. Unfortunately defect generation during the FIB patterning of narrow structures results in severe degradation of the transport properties of the bulk semiconductor. FIB-induced scattering centers have been detected as far as 4 μm away from the irradiated area[2], which puts a severe limitation on the minimum device width. However, such FIB-induced defects could potentially be avoided by suspending the structures on thin membranes in order to limit ion collisional scattering effects. In this presentation we will describe the two-dimensional electron gases (2DEGs) that have been fabricated on thin membranes and the suspended wires we have sculpted using our high resolution gallium FIB nanowriter[3]. Our approach could not only be valuable for extending the limitations of FIB patterning, but it could also have applications in nanoelectromechanical systems.

The implementation of fully suspended GaAs/AlGaAs structures requires the design and growth of special heterostructures by molecular beam epitaxy (MBE). These heterostructures embody a buried, micrometer-thick sacrificial layer of AlGaAs, beneath the 2DEG. This layer has a high Al (>85%) content and can be etched in concentrated HCl selectively to the rest of the heterostructure. The resulting membranes can be as thin as 250 nm.

Standard Hall bars have been patterned using electron-beam lithography. The bars can be functionalized as needed prior to the membrane suspension. An example of such a suspended Hall bar can be seen in Fig. 1. Transport measurements on the membranes show only small degradation of the mobility/density compared to the unetched bars. Using a FIB on such a suspended Hall bar, we can "sculpt" the thin membrane from its side, creating constrictions as narrow as few hundred nanometers. Figure 2 shows FIB-patterned suspended quantum point contacts (QPC) with suspended side gates.

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[1] R. L. Seliger, J. W. Ward, V. Wang and R. L. Kubena, Appl. Phys. Lett. **34**, 310 (1979).

[2] T. Yamamoto, J. Yanagisawa, K. Gamo, S. Takaoka, and K. Murase, Jpn. J. Appl. Phys. **32**, 6268 (1993).

[3] J. Gierak, *Focused Ion Beam Direct-Writing* in *Lithography*, edited by S. Landis, (Wiley-ISTE, 2010), pp. 183-226.

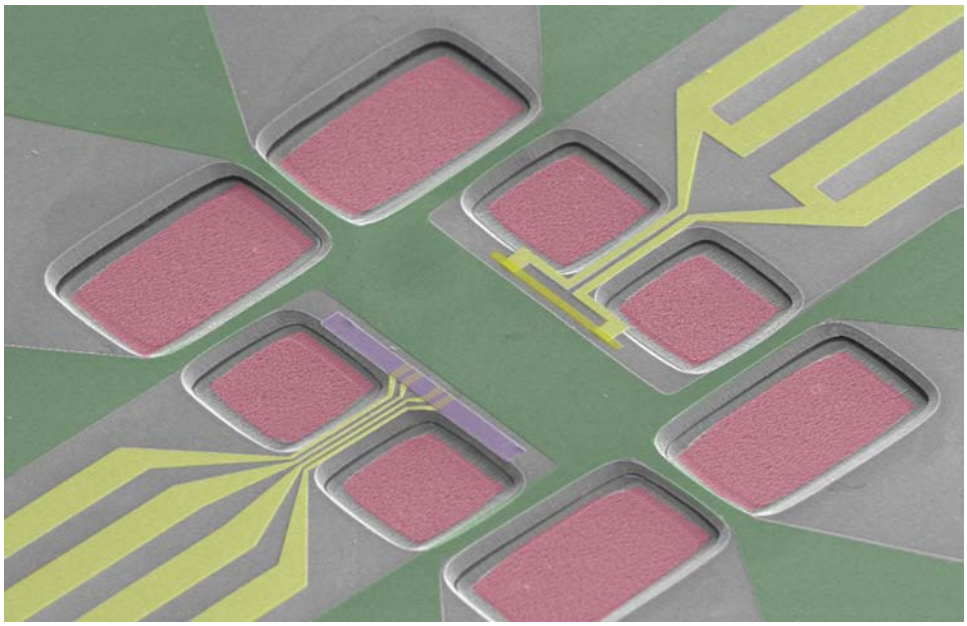

Figure 1: Suspended Hall bar: A colored scanning electron micrograph of a suspended 2DEG. The fully-suspended membrane is also equipped with an NbN thermometer and an Au heater for heat capacity measurements.

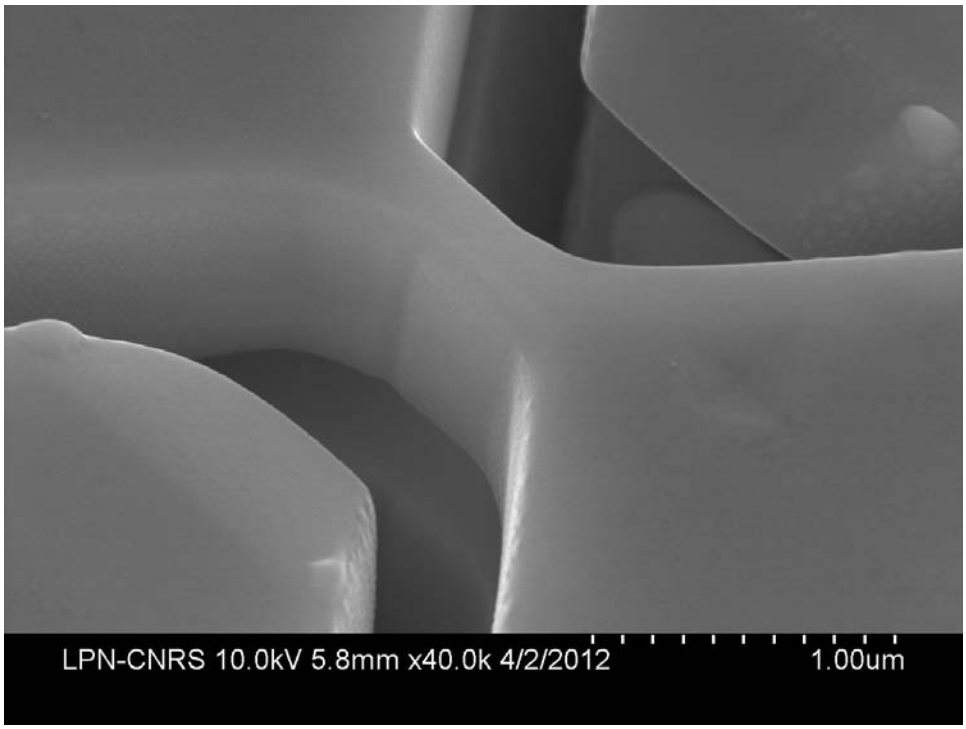

Figure 2: Suspended QPC: A scanning electron micrograph of a suspended QPC with suspended side gates patterned by FIB sculpting of a sully-suspended 2DEG.