Hole density and mobility measurements of two-dimensional hole gasses (2DHG) due to aluminum delta layers in silicon

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Aluminum “delta” layers synthesized on Si(100) by depositing a single layer of aluminum and encapsulating it with silicon are patterned into Hall bars and nano-wires and measured by low-temperature transport. The Al delta layer synthesis process is analogous and complementary to the phosphorus delta layer work but is not compatible with the H-lithography methods used to make P doped nano-devices. However, B and Al delta layers have been theoretically predicted to superconduct at sufficiently high doping densities (> 1 at %), offering the possibility of monolithically joining semiconducting and superconducting quantum information devices.

As summarized with STM (scanning tunneling microscopy) images in Figure 1, Si(100) substrates are prepared by *ex situ* chemical cleaning, followed by *in situ* thermal cleaning treatment. Aluminum deposited onto these surfaces forms a well ordered 2x2 array of atoms, which then incorporate into the surface after a brief, low temperature anneal. The sample is then overgrown with ≈60 nm of epitaxial silicon before removal from the vacuum chamber and patterning into Hall bar devices.

Hall measurements (Figure 2) at <4K confirm the dominant carrier type is holes, with a typical density of $\approx 2 \times 10^{14}$ holes/cm^2, which is slightly larger than the density of deposited aluminum atoms (but within our present uncertainties). Calculated mobilities based on the measured densities range from 10 to 20 cm^2/V-s, depending on details of the anneal and overgrowth. The most promising samples have been cooled below <50 mK, but no evidence of superconductivity has yet been observed. Magnetoconductance measurements as a function of temperature show conduction dominated by "electron-electron" scattering, with a hint of weak anti-localization. We are continuing to optimize the material synthesis, while also etching and measuring nano-wires (down to ~50 nm so far) and other devices. Direct assessment of the Al 3D density by atom-probe and STEM is also in progress.

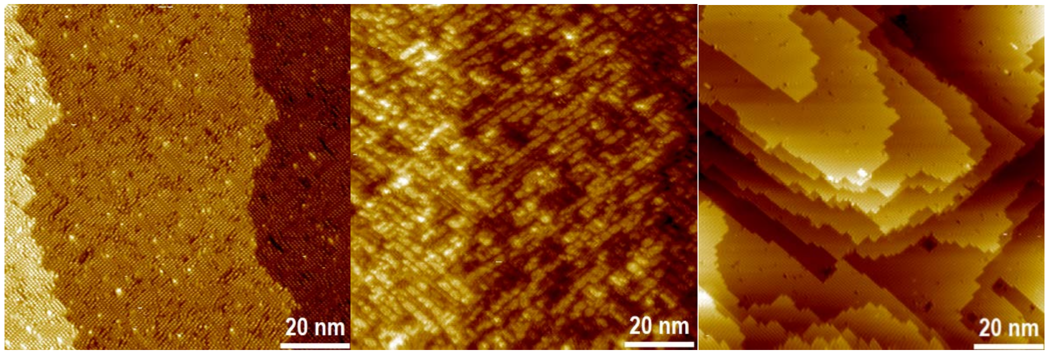

Figure 1: Aluminum delta layer synthesis: Following *in situ* flash-anneal preparation of the Si(100) substrate, (left) a near-saturated layer of aluminum deposited on the surface self-organizes in a 2x2 array. After a brief, low temperature anneal, (center) the Al incorporates into the surface (dark lines) and ejects an equivalent amount of silicon (bright rectangle). Finally, the sample is overgrown with epitaxial silicon to encapsulate the aluminum delta layer (right).

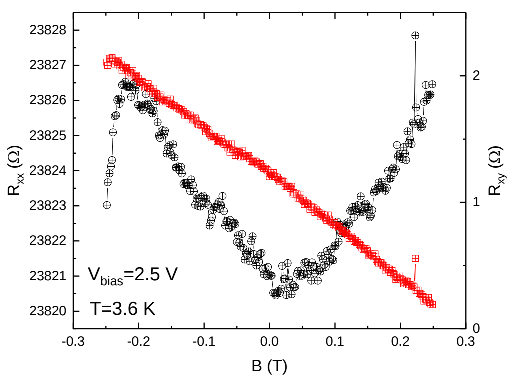

Figure 2: Hall measurements: The synthesized Al delta layer is patterned into a Hall bar by photo-lithography and cooled to <4 K. The R_{xy} (Hall resistance) has a negative slope, confirming hole conduction. Extracted densities and mobilities are typically ~2 x 10^{14} holes/cm^2 and ~15 cm^2/V-s, respectively.