CONTACTS AT THE NANOSCALE: USING SILICON NANOSTENCILS TO MAKE WIRES AND CONTACTS ON ULTRA HIGH VACUUM CLEAVED INSULATORS

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The conductance measurement of single molecules has been a focus of many groups for the past decade. Careful measurement of molecular transport would help pave the way for molecular electronic devices with numerous applications. Despite many attempts, rigorous agreement between theory and experiment remains elusive [1]. In order to close this gap, a detailed knowledge of the environment and contacting geometry is required. To this end, ultra high vacuum (UHV) measurements provide a possible route, however making the connection from the macroscopic realm of cables and measurement devices to the nanometer scale of individual molecules requires a creative mixture of micromachining techniques and understanding of the growth processes at atomic scales.

In order to make electrical measurements at the single molecule level, stencil masks based on silicon membranes have been developed to deposit metals onto atomically flat insulating substrates in UHV. Stencil deposition has the advantages of being a resist free deposition process, and compatible with UHV-clean substrates, such as vacuum cleaved KBr, while providing flexibility in both structures and substrates. [2,3]
In order to make contacts at the nanometers scale but have the flexibility of contacting to millimeter or later deposited contacts we chose to use a two mask process. Using two sets of masks allows a separation of length scales, where nanometer scale openings are present solely in the membrane but the interface to the macroscopic is accessed by a simple millimeter scale contact mask. Samples are created using vacuum cleaved substrates with 2 terminal contacts deposited in situ onto the freshly cleaved face using a 50-75 micrometer copper mask [3]. For the smaller features we use stencil masks created using standard micromachining techniques at the McGill Nanotools facility. Smaller features are deposited using openings as small as 50 nm created in thick silicon membranes with regions thinned using the focused ion beam at the University of Sherbrooke, as shown in Fig 1. These masks are now being used to deposit long tantalum and gold contacts and wires on KBr without removing the sample from vacuum, which bridge the gap given by the initial masking step.

One difficulty of using stencil masks is maintaining the pattern integrity in the face of intrinsic and deposited film stress created by depositing thick films of metal or other materials on the stencil. Efforts have been make to create stabilizing structures and patterns for stencil membranes [4], typically using thin silicon nitride membranes. These can suffer from a difficulty of extending the support structures close to the apertures while avoiding disrupting line of sight for the openings and source. Using single crystal silicon membranes greatly helps alleviate the former, but the latter is still a problem for all stencils. We have created a simple form of support structure in the silicon stencil itself to allow it to resist significant deformation even with high stress metal films while maintaining the aspect ratio near the nanoscale openings.

To further allow the positioning of molecules near electrodes, nanometer size pits have been created in the surface by electron irradiation of the substrate. The pits can be created either the scanning electron microscope (SEM) or the electron beam evaporator. Using the SEM, pits as small as 1-2 nm across have been created and then imaged using atomic force microscopy. These pits can also be used as a template to control the growth of metals and molecules on nanometer length scales. By imaging the metal wires and contact pads with the SEM we can both obtain structural information on the metal contacts and create pits of arbitrary size to which will tend to nucleate near metal structures. Furthermore, as we have also demonstrated, these pits can in turn act as nucleation centers for the growth of molecules and metal clusters, such as gold [5]. Gold clusters will preferentially nucleate on the corners of these pits, and together with the control over the pit size this allows the templating of close proximity metal contacts to individual molecules.

These techniques give us access to all the relevant length scales in which one would like to control the deposition and position of metals and molecules in order to make well characterized conductance measurements, bringing us closer to being able to close the fundamental gaps in molecular measurements between theory and experiment.

References:

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Figures:

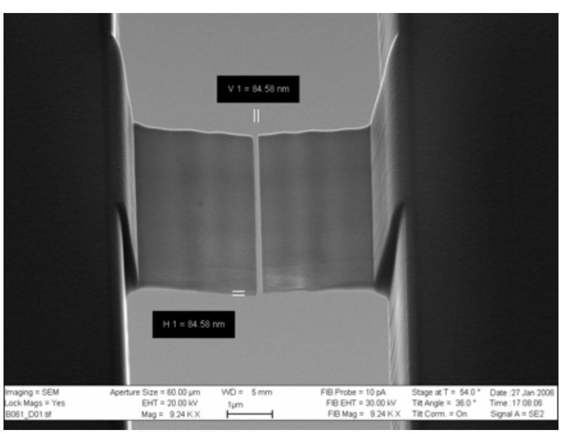

Figure 1: Silicon stencil, 80 nm wire opening