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Vacuum Assisted *ex situ* Lift Out of FIB Prepared Specimens

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Conventional *ex situ* lift out (EXLO) relies on adhesion forces to pick up a specimen with a solid probe tip and place it on a suitable carrier [1-3]. The primary adhesion forces at work are Van der Waals, capillary, and electrostatic forces [3]. New developments in *ex situ* lift out include a new grid carrier design and methods which allow fast and easy manipulation of specimens outside of the costly FIB [3-8]. Once manipulated to this new grid design, the specimen may be further processed via FIB, broad beam ion milling, or plasma cleaning. Specimens can be easily positioned into a backside orientation and then FIB polished, reducing curtaining artifacts [5,6]. EXLO is also amenable to very large specimens routinely available from plasma FIB instruments [7,8]. A single *ex situ* lift out system can support multiple FIB instruments, and when coupled with its speed and ease of use, reinforces its cost effectiveness.

Vacuum micropipetting techniques are well known methods used in cell physiology and micro-robotics [9-11]. The shape of these vacuum grippers may be beveled, bent, or angled to optimize and accommodate the target surface of interest for both the pick and the place step [9-11]. In this paper, we combine a vacuum micropipetting module with an *ex situ* lift out station, making use of both suction vacuum forces and adhesion forces for the Pick&Place™ of a FIB milled specimen onto an EXpressLO™ grid.

First, a hollow glass tube is pulled to a fine point (~ 1 μm) and then beveled to an angle, α, with an opening of ~ 2-4 μm, such that α, plus the probe attack angle, β, = 90^{o} as depicted in the schematic diagram in Figure 1. A completely FIB milled free specimen is prepared as in conventional EXLO. As the shaped hollow probe nears the freed specimen, a valve is opened and vacuum is pulled through the probe (Figure 2a) causing the specimen to stick to the probe tip via suction forces (Figure 2b). The probe tip and specimen is then manipulated to an EXpressLO™ grid. The vacuum valve is closed as the probe tip approaches the grid, using just adhesion forces to hold the specimen. The probe slides through the open EXpressLO™ grid slot (Figure 2c), allowing the specimen to rest on the grid surface in a backside orientation (Figure 2d). The specimen can then be further FIB thinned as before [3-6]. Vacuum pick of specimens, combined with the EXpressLO™ place method, increases specimen manipulation accuracy and positioning reliability to EXpressLO™ grids which are uniquely designed for direct analysis or return to the FIB for further processing.

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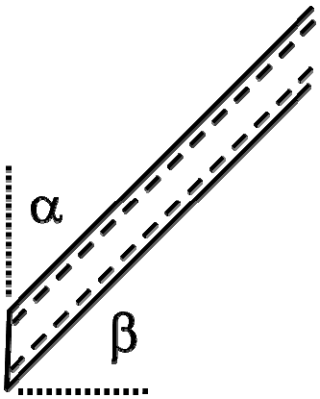

Figure 1. A schematic diagram of the hollow glass tube geometry.

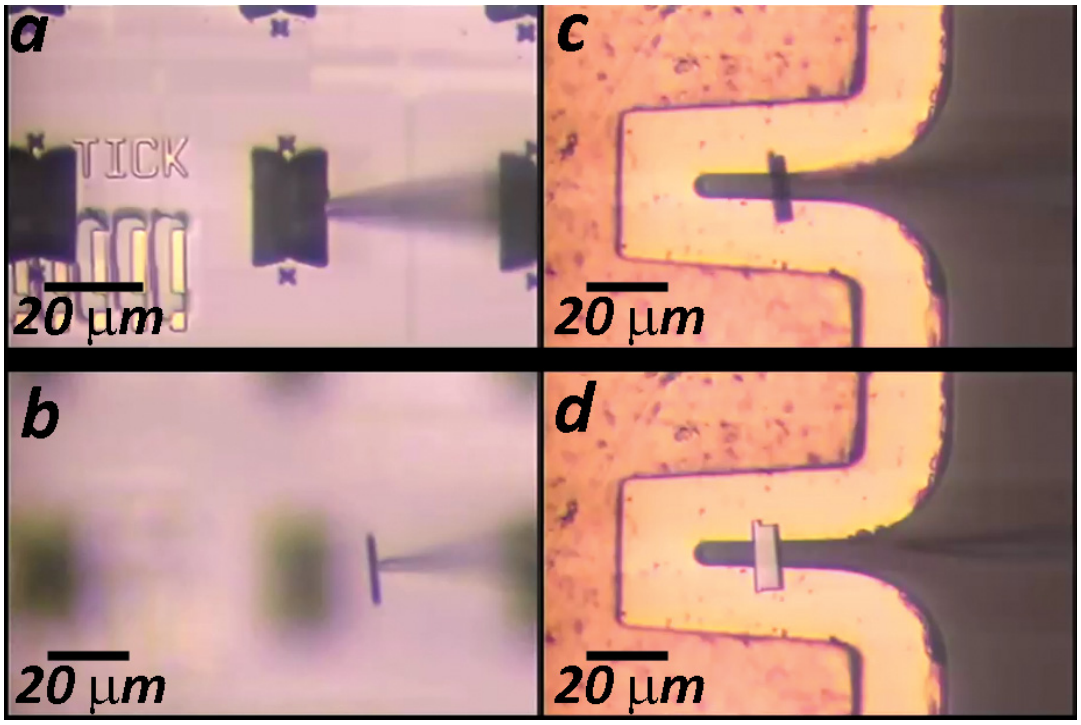

Figure 2. Light optical micrographs of EXpressLO™ Pick&Place™ lift out and manipulation with a vacuum micropipette. (a) The vacuum valve is opened as the hollow probe nears the FIB milled free specimen. (b) The specimen pick is performed. (c) The vacuum valve is closed and the specimen is centered and placed on the EXpressLO™ grid while sliding the probe through the open slot. (d) The specimen rests on the EXpressLO™ grid in a backside orientation.

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