Routine Backside FIB Milling With EXpressLO™

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Abstract

A new method and grid design is described for implementation of ex-situ lift-out of FIB prepared specimens. This technique negates all prior disadvantages to ex-situ lift-out and provides a method for higher throughput and re-thinning of ex-situ specimens. In particular, this method allows for easy, fast, and routine manipulation for subsequent backside FIB milling and analysis.

Introduction

It is generally accepted that focused ion beam (FIB) ex-situ lift-out (EXLO) specimen preparation for transmission electron microscopy (TEM) and other analytical techniques has a higher throughput than in-situ lift out (INLO) methods [1]. In addition, since ex-situ lift out is performed outside of the FIB or FIB/scanning electron microscope (SEM) instrument, EXLO may save costly instrumentation time compared to INLO.

The primary disadvantage to conventional EXLO is the difficulty of re-thinning a specimen once the specimen is manipulated to the usual carbon, formvar, or holey carbon film. In addition, the carbon or formvar film supporting the specimen may interfere with certain TEM methods such as electron energy loss spectroscopy (EELS) or electron holography. Porous and delicate specimens are also difficult to prepare using EXLO methods since they may fail or break along weak interfaces when FIB milled to electron transparency. Since EXLO specimens are supported on organic films they cannot be plasma cleaned because the film, and thus the specimen, may be removed by the process.

Conventional EXLO methods consist of FIB milling a specimen completely to electron transparency prior to lift out. Since FIB milling is performed while the specimen is surrounded by trench walls, the specimen may be predisposed to redeposition artifacts [2]. Redeposition artifacts can also be problematic in confined trenches using broader ion beams that are synonymous with low energy FIB milling techniques.

Using newly developed methods, EXpressLO™ may be used to manipulate ***thin or thick specimens***, in any orientation, to a newly designed grid such that the specimen may be further thinned (if required) by conventional FIB methods or other broad beam milling techniques. In addition, EXLO manipulation to a grid followed by further thinning reduces possible redeposition issues exacerbated by FIB milling in confined trenches. Manipulating specimens to a grid allows for a better heat sink and also provides mechanical stability for the specimen during subsequent further thinning.

Another advantage to EXLO is that the specimen is not adhered to the manipulator in a fixed orientation. Since static forces attach the specimen to the grid, the specimen can be easily maneuvered and flipped around in any orientation. Thus, fast and easy manipulation in any direction allows the specimen to be positioned into a backside orientation to reduce curtaining artifacts of multi-layered semiconductor specimens [3]. Indeed with EXpressLO™, backside manipulation may be performed routinely and has the potential to become the norm. Routine backside EXLO and subsequent FIB thinning methods are detailed below.

Experimental Methods

Using the EXpressLO™ method, a specimen may be FIB milled to electron transparency or thicker, say 1-2 μm in thickness, as shown in Figure 1. The specimen is then lifted out using a hydraulic micromanipulator or similar as per the usual EXLO method [4]. Conventional EXLO uses a glass rod pulled to a fine point. Static attraction is used to "pluck" the specimen from the trench. If the specimen is completely FIB milled free, the lift-out procedure itself should take no more than ~ 30 seconds to perform.

Once the specimen is lifted out, it is manipulated to a newly designed grid carrier which allows the specimen to be transferred back into the FIB/SEM for further milling. The specimen support area of the grid contains a slit to allow for TEM analysis and further FIB milling of both specimen surfaces if needed as shown in figure 2. In addition, the specimen may be further thinned via broad beam ion milling or directly analyzed using other methods [5].

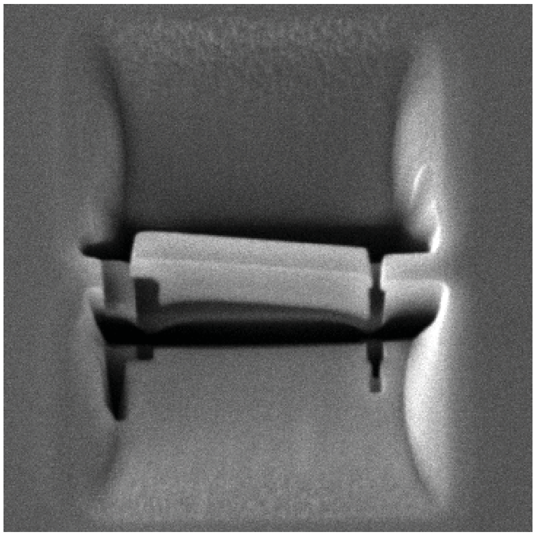

Figure 1: An example FIB milled specimen ready for EXLO. The specimen is 1-2 μm thick.

As mentioned, EXLO relies on static attraction of the glass rod to the specimen. Therefore, the specimen is not rigidly fixed to the probe in a single orientation. Thus, the specimen can be easily maneuvered, oriented, and repositioned again and again as needed until a satisfactory orientation of the specimen on the grid carrier is achieved. Manipulation of the specimen to the grid surface can take between ~ 30 seconds to at most a few minutes depending on the exact orientation desired. Thus, the entire EXpressLO™ manipulation process is extremely fast and does not require expensive FIB/SEM time to perform the lift-out.

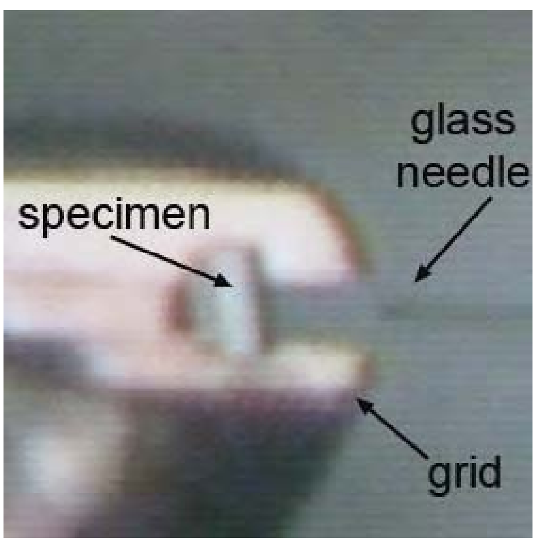

Figure 2: EXpressLO™ of a specimen into a backside orientation to a newly designed grid carrier.

In Figure 2, a semiconductor specimen has been directly manipulated via EXpressLO™ into a backside orientation, i.e., the Si substrate is positioned such that it will be FIB milled prior to the multi-layers. That is, the Si side of the specimen is nearest to the slit opening. A smooth, clean, and flat grid surface ensures that the FIB milled specimen directly adheres to the grid carrier via surface tension forces.

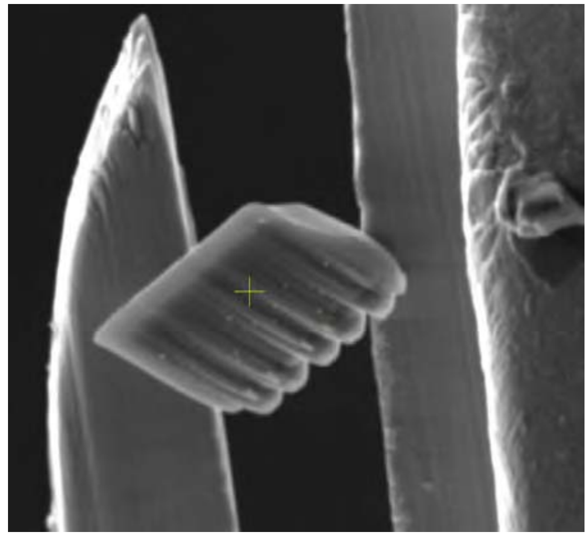

Figure 3: An SEM image of an EXpressLO™ specimen manipulated into a backside orientation after the grid/specimen assembly is put back into the FIB/SEM for further thinning.

After lift-out, the grid/specimen assembly is inserted back into the FIB/SEM for further thinning. Figure 3 shows an SEM image of an EXpessLO™ specimen oriented for backside FIB milling. If desired, electron beam and/or ion beam deposition can be used to provide additional support for the specimen to the grid (see Figure 4). Since the Si substrate itself can protect the multi-layers, another deposition layer (e.g., Pt, W, C, etc.) for the top of the specimen is not needed. The omission of this traditional deposition step provides additional specimen preparation throughput in the FIB milling procedure.

Figure 4 shows an SEM image of the final backside FIB prepared specimen and EXpressLO™. As evident, there is plenty of Si remaining and the substrate provides sufficient protection for the semiconductor multi-layered structure.

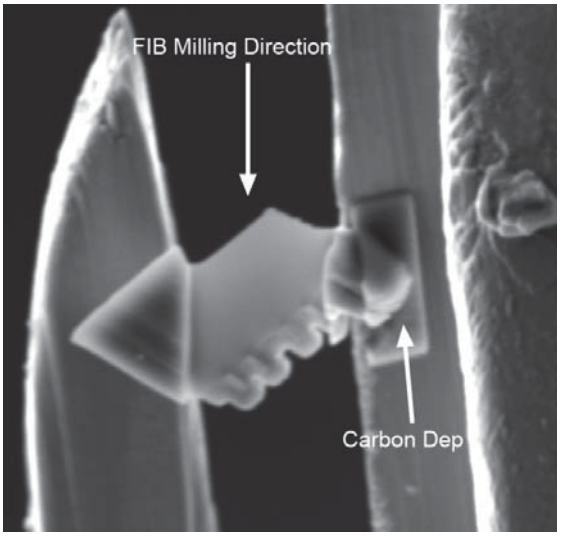

Figure 4: Optional ion beam assisted carbon deposition further secures the specimen to the grid. Then the backside oriented specimen is FIB milled to electron transparency from the Si side of the specimen.

Results and Discussion

Figure 5a shows a low magnification TEM image of a semiconductor specimen manipulated to a backside orientation using the EXpressLO™ method and then FIB milled from the Si substrate side of the specimen. The uniform contrast in the Si substrate is proof of the absence of curtaining artifacts usually patterned from the multi-layers since FIB milling occurred from the Si side of the specimen. Figure 5b shows a higher magnification TEM image of the gate region within this semiconductor device. The Si substrate shows diffraction contrast due to strain under the gate and W plugs, but is devoid of any contrast changes due to thickness changes stemming from curtaining artifacts.

Conclusions

This EXpressLO™ method combines the high throughput of EXLO with the flexibility and ability to re-thin a specimen in a backside orientation. EXpressLO™ for backside milling is fast, easy, routine, reproducible, and may allow for backside milling in every opportunity possible [6].

References

[1] L.A. Giannuzzi and F.A. Stevie (eds.) Introduction to Focused Ion Beams, Springer (New York 2005) pp. 201-228.

[2] S. Rajsiri et al., "FIB Damage in Silicon: Amorphization or Redeposition?," Microscopy and Microanalysis, Vol. 8, Suppl. 2, (2002), 50-51.

[3] S.M. Schwarz et al., "Avoiding the Curtaining Effect: Backside Milling by FIB INLO," Microscopy and Microanalysis, Vol. 9, Suppl 2, (2003), pp. 116-117.

[4] L.A. Giannuzzi et al., "Focused Ion Beam Milling and Micromanipulation Lift-Out for Site Specific Cross-Section TEM Specimen Preparation," Mat. Res. Soc. Symp. Proc. Vol. 480 (1997), MRS, pp. 19-27.

[5] F.A. Stevie et al., "Application of Focused Ion Beam Lift-Out Specimen Preparation to TEM, SEM, STEM, AES and SIMS Analysis," *Surface Interface Analysis*, (2001), Vol. 31, pp. 345-351.

[6] Lucille A. Giannuzzi, this technique and design is patent pending.

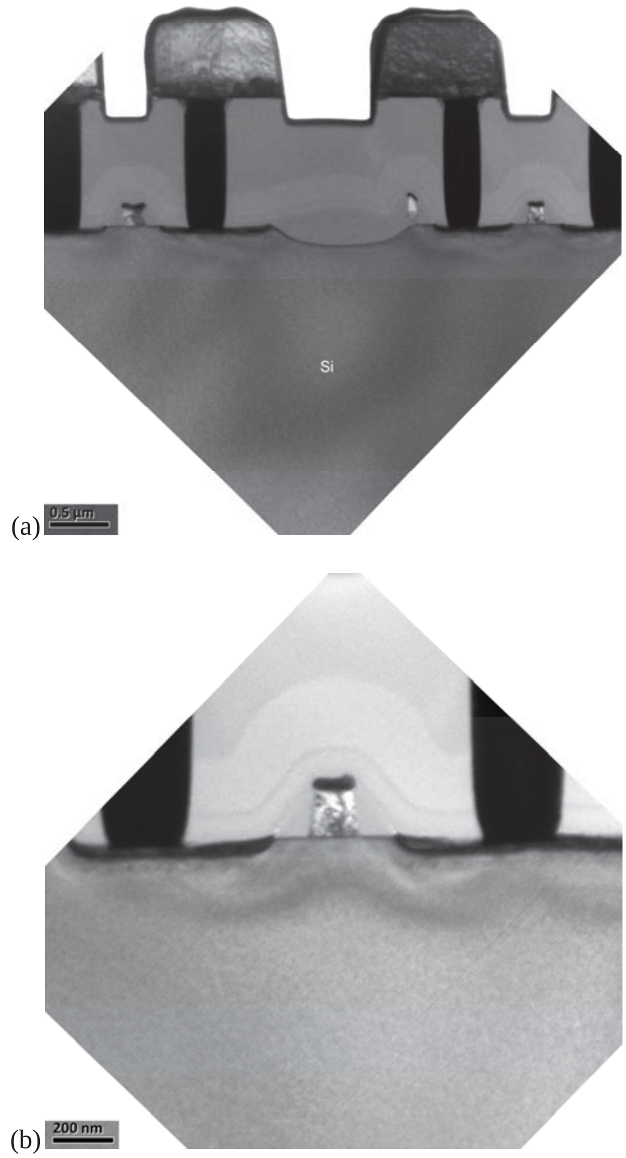

Figure 5: (a) Low magnification TEM image of the EXpressLO™ specimen manipulated and FIB milled in a backside orientation shows the elimination of curtaining artifacts. (b)TEM image of the gate region in the backside prepared specimen.