CONTROLLING THE DIMENSIONS OF NANO-STRUCTURED MATERIALS USING FIB SEM

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Techniques for characterization and methods for fabrication at the nano-scale are becoming more powerful, giving new insights into the spatial relationships between nanostructures and greater control over their development. A case in point is the application of state-of-the-art focused ion beam technology (FIB), in combination with high-performance scanning electron microscopy (SEM), giving the ability to use either ions or electrons to perform advanced nanofabrication, via sputtering or chemical vapor deposition. For example, Figure 1 shows a photonic array, milled into silicon using a focused gallium ion beam and subsequently imaged with an electron beam.

Numerous parameters must be considered in order to achieve high quality results, particularly where stringent critical dimensions are required or when dealing with challenges such as electrically insulating and/or soft materials. Critical dimensions and pattern profiles can be well controlled by the use of adequate patterning strategies. Milling rates and the uniformity of patterns, for example, depend on the exposure regime. Dwell time, refresh time, single-pass or multi-pass execution of individual pattern elements, the definition of leading edges, consideration of re-deposition in the milling order and a material-dependent selection of the pitch (i.e. overlap) are all important aspects for successful prototyping. As an example of the importance of choosing the right milling strategy, Figure 2 helps to illustrate two different approaches. Figure 2(a) shows two patterns FIB-milled using short pixel dwell times and multi-pass milling to achieve the required depth. Although the direction of the scan was left-to-right in the left-hand pattern, and bottom-to-top in the right-hand pattern, this has had no effect on the result. In figure 2(b) an electron beam lithographic approach has been used, in which FIB milling was performed in a single pass of the beam, and a long dwell time. The scan directions are the same as described for Figure 2(a). It can be seen that there are pronounced milling artifacts and redeposition, reflecting the direction of the scans and the leading edge. As this example helps to show, evaluation of the relevant factors can have a dramatic effect on the precision of FIB-patterning and CVD, and is essential for high-quality fabrication of structures such as Fresnel zone plate lenses [1], photonic arrays [2] and deposition of 3-dimensional structures [3].

There are many potential applications of FIB SEM involving soft and/or electrically insulating materials such as polymers, ceramics, glasses and biological specimens. However, these are somewhat demanding due, to a large extent, to the accumulation of positive charge during ion beam irradiation and the further formation of a positive surface potential as a result of secondary electron emission. In order to truly extend our capabilities in this regard, we must address the issue, since the resulting image drift can have significant consequences upon the accuracy and quality of FIB milling, imaging and CVD. Whilst the application of an electrically conductive coating to the specimen surface can be adequate to overcome charging problems associated with the primary ion beam, it is not always appropriate or practical to apply such a coating, and so other methods of charge control are needed. For example, an ancillary electron ‘flood gun’ can be used to deliver low energy electrons to the specimen surface, thereby helping to maintain a charge balance. We have developed a method for suppressing ion beam drift using a defocused, but site-specific, low energy primary electron beam, and have derived an analytical method to correlate the ion and electron beam energies and currents with other parameters required for electrically
stabilising these challenging materials [4]. This enables us to create high resolution microstructures such as nano- and micro-fluidic channels in electrically insulating substrates.

References

![Figure 1. Split ring resonators FIB milled in silicon. The optical properties of this electromagnetic meta-material depend on accurate control of dimensions.](image1)

![Figure 2. Multi-pass (a) vs single pass (b) milling strategies lead to very different pattern profiles.](image2)