Focused Ion Beam Processing of Polymers: Pushing the Limits by Alternative Patterning Strategies

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During the last decade focused ion beam (FIB) processing has become an essential tool for sub-surface (3D) metrology and the site specific fabrication of ultrathin lamellas suitable for transmission electron microscopy. Beside these inspection and preparation related applications, FIB processing also attracted enormous attention as rapid-prototyping tool with respect surface modification and 3D structuring down to the lower nanometer scale. However, when combined with low melting materials, such as polymers or biological specimens, morphological instabilities and severe chemical damage are often observed results giving this combination the reputation of being very complicated or even impossible. To go beyond current limits a fundamental insight concerning local temperatures including their spatial and temporal evolution during FIB processing is first needed. Based on such knowledge individual effects could be identified and appropriately counteracted as discussed in this contribution.
In the first part, we present an approach which uses ion trajectory simulations (Ga^+) as input data for a thermal-spike model. This allows the prediction of local temperatures and its lateral distribution during FIB processing in low melting polymers (Figure 1a). Taking into account the thermal behavior of polymers, combined simulations and calculations reveal very good agreement with real FIB experiments on polymers (Figure 1b) confirming the suitability of this combined approach to predict local temperatures and its spatial and timely evolution. In a second step we identify a technically induced heat component which originates from typically used patterning strategies. Based on the gained knowledge we introduced an alternative patterning strategy which effectively eliminates this technically induced contribution. A multi-technical approach confirms the minimization of chemical damage at maximized morphological stability (Figure 2) which does require neither increased process times nor reduced beam currents or low-temperature sample stages for polymeric materials. By that, the new approach reduces morphological / chemical consequences to a minimum given by the intrinsic and unavoidable limit of individual ion-matter interactions. This opens new capabilities which have been considered as very complicated or even impossible in the past.

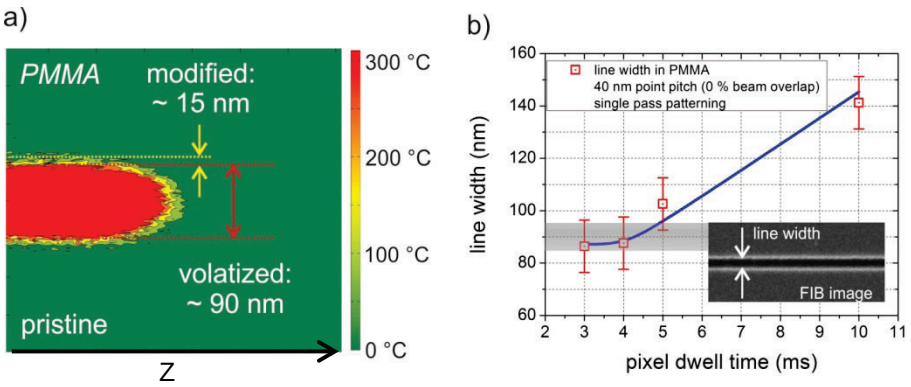

Figure 2: (a) calculated temperature distribution along Z for PMMA using the combined SRIM / thermal spike model approach. The different colors are adapted to thermodynamically relevant regions: green - pristine (below melting point), yellow - liquid / modified regions (above melting point), and red - volatized. (b) shows experimental single line widths in dependency on pixel dwell times patterned in PMMA (red squares) with regular patterning strategies revealing minimum line widths in the same range as predicted by the simulations as indicated by the grey bar (compare to (a)). The inset gives a representative FIB image of shortest dwell times in PMMA.

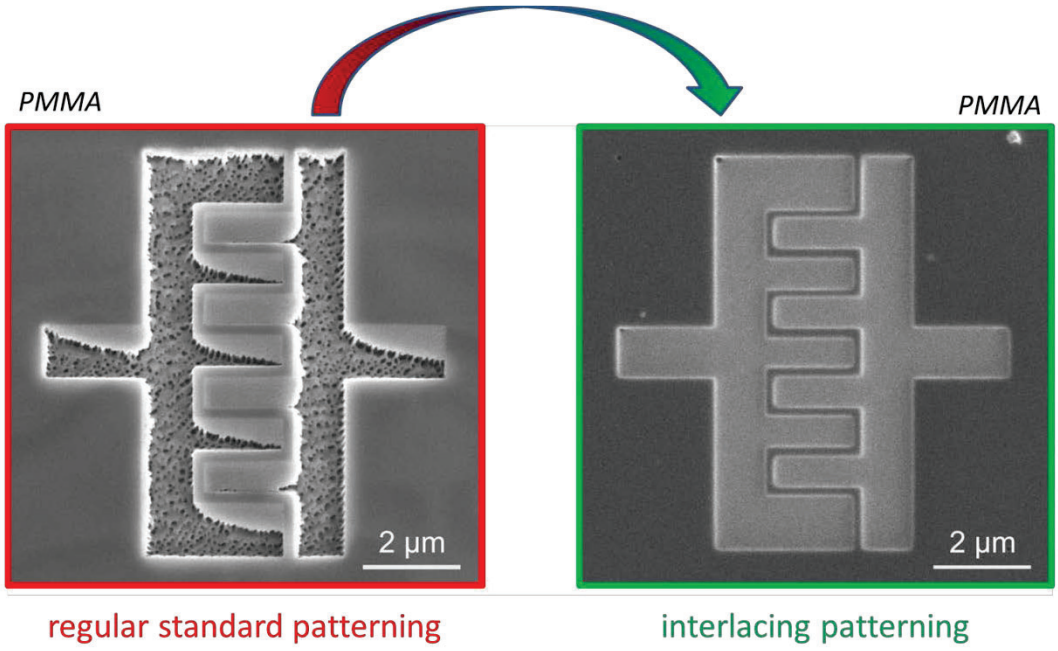

Figure 2: direct comparison of a PMMA sample structured via Ga^+ FIBs at 30 kV / 500 pA with standard raster- (left) and alternative interlacing-strategies (right). Please note, both patterns use the same process time and were prepared at room temperatures in a single pass. The massive improvement clearly demonstrates the potential of this new and simple patterning approach which bases on the systematic re-arrangement of patterning points.