Ga^+ Focused Ion Beam Micromachining of Thermoplastic Polymers

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Commercially available Ga^+ focused ion beam (FIB) instruments with nanometer size probes provide in situ materials removal (sputtering) and addition (deposition) capabilities over a wide range of material. These spatially precise processes enable a wide range of nanofacbrication techniques[1]. While an established although still expanding knowledge base of FIB methodologies for hard materials exists, FIB methodologies for nanomachining of soft materials such as biological and polymeric materials are underdeveloped. As FIB is increasingly utilized for specimen preparation of polymeric materials, it has become necessary to formulate an information base that will allow established FIB techniques to be generalized to this spectrum of materials.

FIB micromachining of polymers is likely a complex process dependent on both the polymer's properties and FIB beam parameters[2]. In an effort to make the existing FIB nanomachining procedures more universally applicable, the interrelationships between the physical properties of target materials, variable FIB parameters, and the efficiency of the FIB nanomachining process are examined. The roles of beam current, beam overlap and pixel dwell time are considered as applied to FIB nanomachining of four different thermoplastic polymers: 1. low density polyethylene (LDPE), 2. high density polyethylene (HDPE), 3. polystyrene (PS), and 4. nylon 6 (PA6). An FEI Quanta 3D FEG is used for all FIB experiments in this study.

Ga^+ FIB material removal rates (MRRs) of these technologically important polymers were experimentally determined (*Figure 1*). It was also determined that irradiation effects such as the cross linking to chain scissioning ratio of each polymer can be used to explain and predict trends in the Ga^+ FIB micromachining rate of all polymers in this study. MRRs were found to be lower in polymers with radiation resistant constituents (e.g. PS), higher crystallinity (e.g. HDPE vs LDPE), and with increasing Ga^+ dose (*Figure 2*).

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[1] Giannuzzi, L. A., & Stevie, F. A. (2005). Introduction to Focused Ion Beams: Instrumentation, Theory, Techniques, and Practice. New York, NY, USA: Springer.

[2] Fink, D. (2004). Fundamentals of Ion-Irradiated Polymers. Berlin, Germany: Springer.

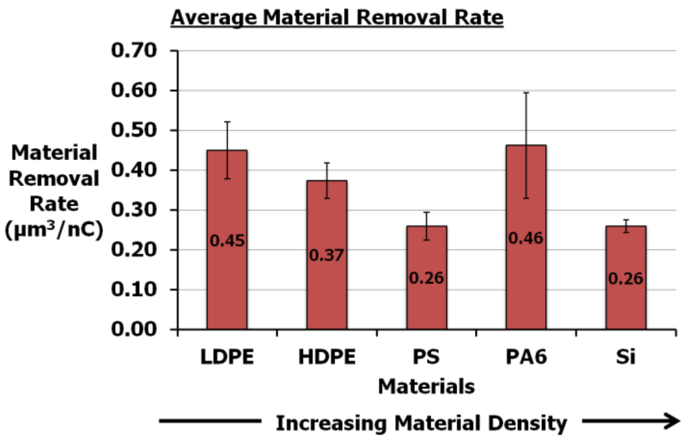

Figure 1: The average MRR of the polymers on pristine polymer surfaces in this study are displayed. The average MRRs of silicon under identical sputtering conditions are also included. The high MRR of PA6, even though it is denser than all other polymers in this study, can be attributed to the cross link to scission chemical modification yield ratio. PA6 has an equal probability of crosslinking as it does to chain scissioning (i.e. G(X)/G(S) = 0.99) due to the simultaneous process of chain cleavage and cross linking.

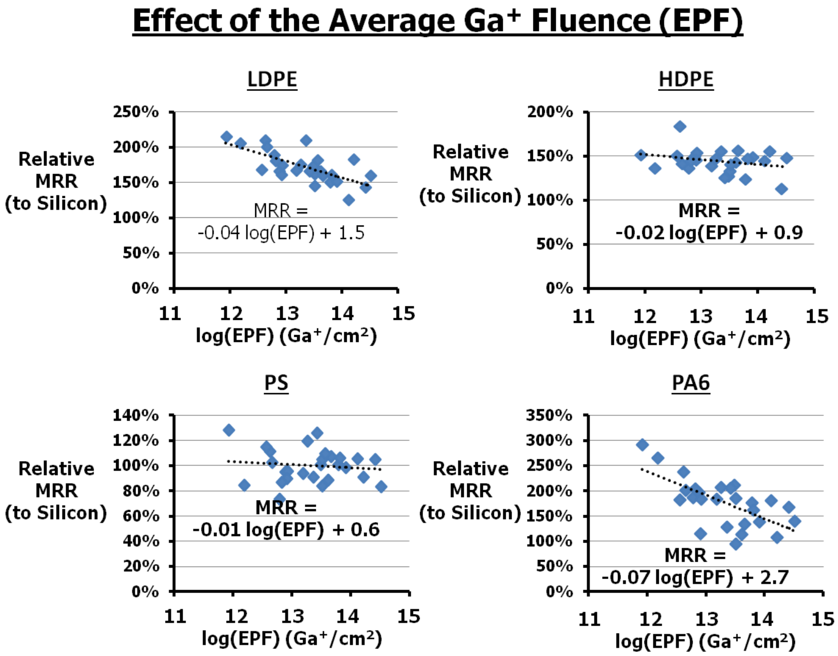

Figure 2: The relative MRR of each polymer is displayed as a function of effective pixel fluence (EPF) presented in log base 10 graphs. In general, the average MRR decreases with for all polymers in this study as the EPF increases, as indicated by the negative slope of the trend lines. EPF generally increases with increasing beam current, beam overlap, or pixel dwell time.