Mixture of ZEP and PMMA with tunable sensitivity as a liftoff layer with controllable undercut

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Lift-off process is a popular method to pattern metals, especially for the noble metals that are hard to dry-etch. For a "clean" liftoff process, an undercut profile is greatly desired. Various methods have been developed to create the undercut profile, using either tri-layer (resist/hard mask/polymer) or bi-layer (resist/polymer) stack structure, with the latter apparently being simpler than the former.

Previously, several combinations of the bi-layer films have been demonstrated to achieve an improved liftoff process. A film stack of high molecular weight (Mw) PMMA/low Mw PMMA can provide a certain degree of undercut profile since the low Mw PMMA has higher sensitivity than the high Mw one, yet for chain scission resist, the dependence of sensitivity on Mw is very week. Alternatively, a copolymer of PMMA-co-PMAA can be used as the under-layer as it is more sensitive than the top layer PMMA. A third liftoff polymer is LOR that is based on poly (dimethyl glutarimide) (PMGI), for which the amount of undercut can be adjusted by the dissolution time of LOR[1]; yet wet etching/dissolution is not a well controllable process. ZEP can also be used as the bottom layer as it is more sensitive than PMMA[2], but the undercut would be too large since ZEP is ~3× more sensitive than PMMA. For ZEP resist (as top layer), besides LOR, PMMA has also been employed as a bottom layer that is more sensitive than ZEP when using undiluted MIBK as developer[3].

A resist with tunable sensitivity is apparently the most desirable, as it can offer a controlled amount of undercut. Ideally, a large undercut profile is preferred to enable the liftoff of very thick metals. But too large undercut may lead to the collapse of the top resist layer onto the substrate, and this will be worse for dense structures.

In this study, we will show that a simple mixture of PMMA (Mw 996 kg/mol) and ZEP can offer tunable sensitivity by adjusting the ratio of the two resists dissolved in anisole. As an example, the contrast curves of pure PMMA, pure ZEP, and the 1:1 mixture of the two are shown in Figure 1, which indicates that the 1:1 mixture has a sensitivity in-between that of pure PMMA and ZEP resist. Higher/lower sensitivity would be attained by increasing/decreasing the ZEP content in the mixture. Using PMMA as top layer resist and pure ZEP or the 1:1 mixture as the bottom layer, the structure after 1 min development in amyl acetate (that is developer for both PMMA and ZEP resist, as well as the mixture) is shown in Figure 2, which indicates the pattern was deformed or even detached due to the too large undercut when using pure ZEP as under-layer.

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[1] Y. Chen, K. Peng, Z. Cui, "A lift-off process for high resolution patterns using PMMA/LOR resist stack", Microelectron. Eng., 73-74, 278 (2004).
[2] I. Maximov, E. L. Sarwe, M. Beck, K. Deppert, M. Graczyk, M. H. Magnusson, L. Montelius, "Fabrication of Si-based nanoimprint stamps with sub-20 nm features", Microelectron. Eng., 61–62, 449 (2002).
[3] L. An, Y. Zheng, K. Li, P. Luo, Y. Wu, "Nanometer metal line fabrication using a ZEP520/50 K PMMA bilayer resist by e-beam lithography", J Vac. Sci Technol. B 23, 1603 (2005).

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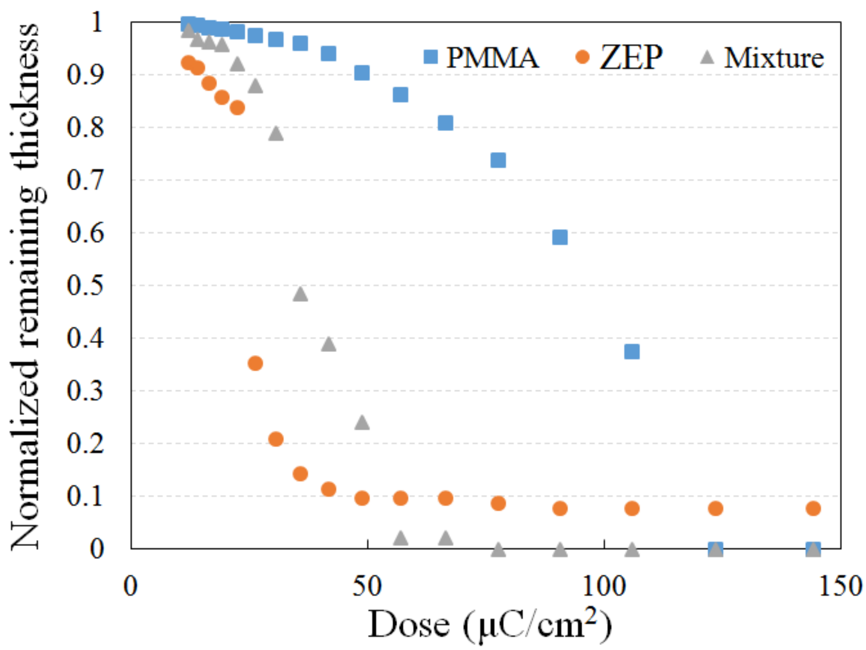

Figure 1 The contrast curves for pure PMMA, pure ZEP, and 1:1 mixture of PMMA and ZEP.

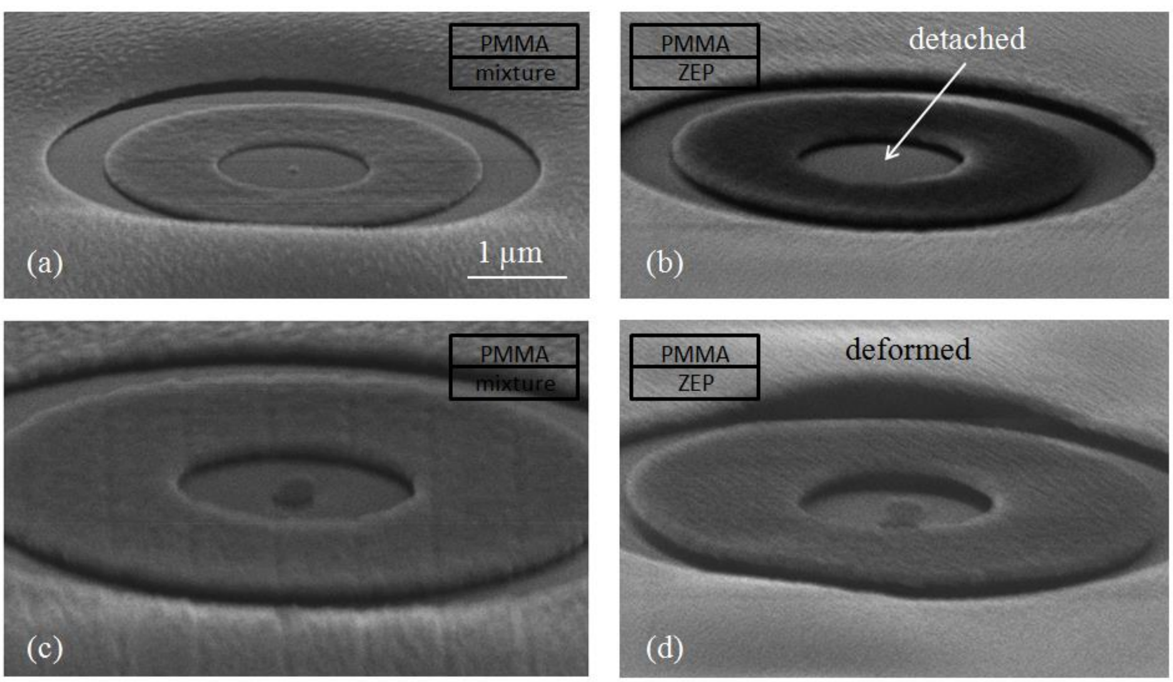

Figure 2 The double-ring pattern after development using amyl acetate for 1 min. (a) & (c) The 1:1 mixture as under-layer; (b) & (d) Pure ZEP as under-layer. Undercut profile is visible for all the images. When using ZEP as under-layer, due to too much undercut, the central pillar was detached (b), or the structure nearby was deformed (d).