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Publication Date

2011-09-01

EUV learning at the 16-nm node and below

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Abstract-- Microfield exposure tools (METs) play a crucial role in the development of extreme ultraviolet (EUV) resists and masks. These tools, however, are currently limited to a numerical aperture of 0.3 limiting their use for addressing resist development at the 16-nm half pitch node and below. The utility of these tools can be extended by employing modified illumination techniques as is done on the SEMTECH Berkeley MET. Using conventional illumination this tool is limited to approximately 22-nm half pitch resolution, whereas with modified illumination the resolution can be extended to 12 nm. In practice, printing down to 15-nm half pitch has been demonstrated using an imageable hardmask resist material. This was accomplished employing a method referred to as pseudo phase shift mask which allows both optical and mask limitations to be mitigated.

I. INTRODUCTION

With the delivery of extreme ultraviolet (EUV) pilot line tools underway, advanced resist development activities have moved on to 16-nm and below. Such extendibility questions are best addressed using research tools like the SEMATECH Berkeley microfield exposure tool (BMET) [1]. Installed at Lawrence Berkeley National Laboratory's Advanced Light Source facility, the BMET benefits from the unique properties of synchrotron light enabling research at nodes generations ahead of what is possible with commercial tools. An example of the advanced capabilities afforded by the synchrotron implementation of the BMET is its lossless fully programmable coherence illuminator [2] and pseudo phase shift mask capabilities [1]. Using these systems, k_1 factors approaching the 0.25 limit can be attained. Given the BMET numerical aperture (NA) of 0.3, this translates to an ultimate resolution capability of 12 nm.

In this paper we review the progress in EUV resists with both chemically amplified and non-chemically amplified materials.

II. TECHNICAL WORK PREPARATION

Owing to the significant challenges in developing high power EUV sources, the focus of EUV resist development has been on chemically amplified resists. Despite the intrinsic diffusion limitations such material suffer from, tremendous resolution progress has been made since the BMET was first brought online in early 2004. At that time, the best EUV resists were performing at a level of approximately 45 nm. By 2008, we had seen a reduction by more than a factor of two with moderate losses in sensitivity. As demonstrated in Figure 1, however, progress in the ultimate resolution of chemically amplified resists stalled in 2008 with arguably no progress since that time.

These results raise the question of tool limitations. Although the NA and illumination capabilities of the BMET should support significantly better resolution, the tool does not include aerial image monitoring capabilities

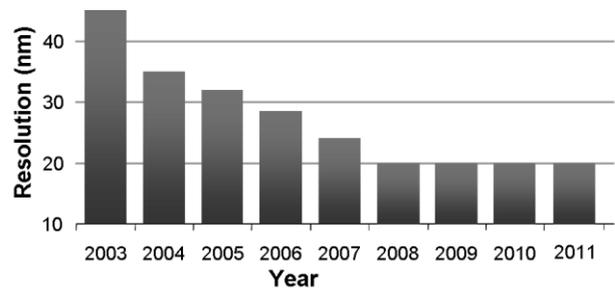


Fig. 1. Ultimate resolution in chemically amplified EUV resist.

that could be used to verify the expected resolution. Thus the only way to prove that the tool is not the limitation, is to find a resist that supports higher resolution than the chemically amplified materials shown in Fig. 1. To address this concern, a non-chemically amplified imageable hardmask material provided by Inpria Corporation has been employed [3].

Figure 2 shows imaging results obtained using this material under dipole illumination as well as the predicted aerial image contrast. Excellent agreement between the predicted contrast and imaging performance is found indicating that the tool is indeed operating as expected and thus validating the results in Fig. 1.

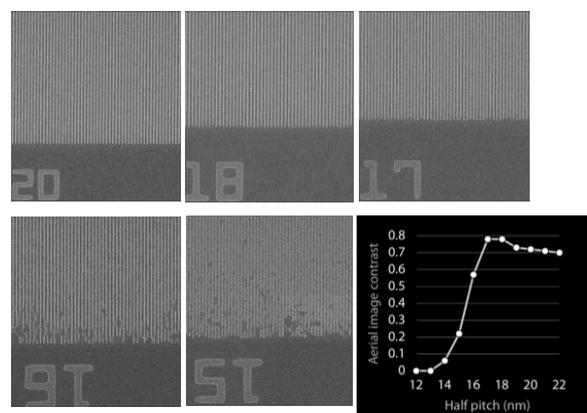


Fig. 2. Printing in non chemically amplified imageable hardmask resist compared to predicted aerial image performance.

Figure 2 demonstrates that for this resist, we are indeed tool limited. In order to test the ultimate performance of this resist, an even more aggressive illumination must be used than the 18-nm optimized dipole used for Fig. 2. To simultaneously address any mask limitations that might also be playing a role, the pseudo phase shift mask technique [1] is employed. Using this method, a conventional binary amplitude mask can be made to act as a chromeless phase shift mask which enables frequency doubling of the pattern. Figure 3 shows printing performance in the Inpria material using this illumination. Resolution down to 15 nm is demonstrated.

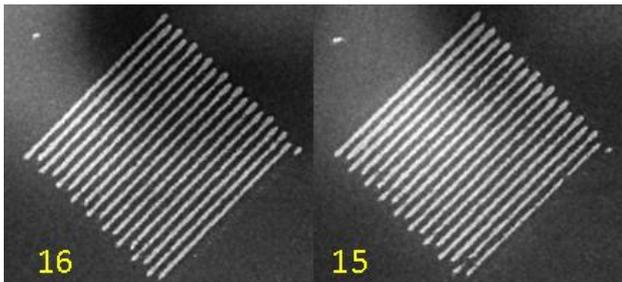


Fig. 3. 16 and 15 nm half pitch lines printed in the Inpria imageable hardmask material using psue phase shift mask.

If the plot from Fig. 1 is expanded to include non-chemically amplified resists, and in particular the Inpria materials, a less pessimistic picture of the progress arises as shown in Fig. 4. It is important to note that these resolution gains have not come without a tradeoff. The sensitivities for the highest resolution materials in 2010 and 2011 were 40 and 70 mJ/cm², respectively.

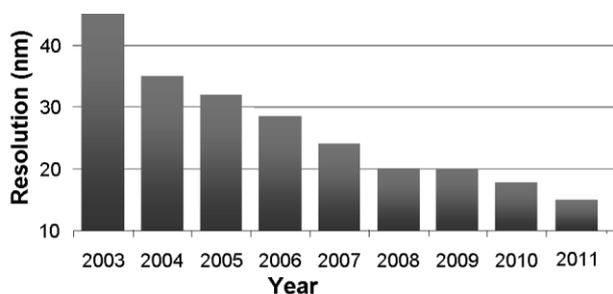


Fig. 4. Ultimate resolution progress including non-chemically amplified EUV resist.

To demonstrate that these new resolution capabilities are truly due to the resist and not the solely the pseudo phase shift mask method, we apply the same method to the highest performing chemically amplified resist tested to date. Figure 5 shows the results, again demonstrating a resolution limit of approximately 20 nm as had previously been found using dipole illumination and shown in Fig. 1.

Another major concern for resist development is line-edge roughness (LER). Unlike resolution, LER has yet to meet even the 22-nm half pitch targets. Figure 6 shows LER and sensitivity results for four of the best performing chemically amplified resists at 22-nm half pitch. We see that performance is quite far from the 1.6-nm target.

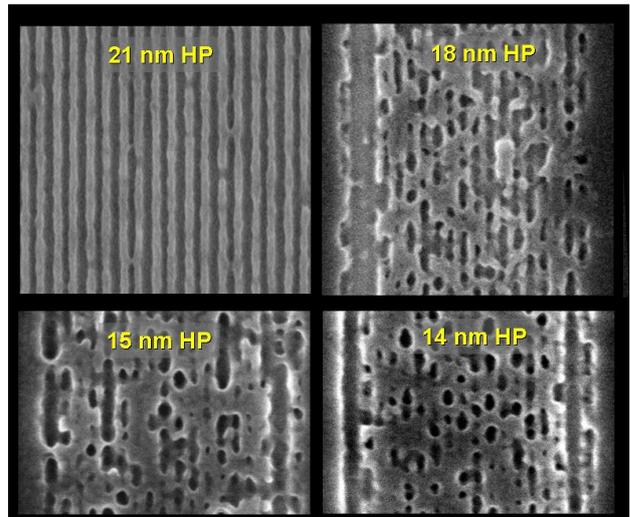


Fig. 5. Imaging in highest performing chemically amplified resist using pseudo phase shift mask method.

III. SUMMARY

Champion EUV resist resolution from a conventional projection lithography system has been pushed to below 16 nm. This, however, was achieved in a non-CAR material. Ultimate resolution progress in CAR materials has been stalled at approximately 20-22-nm half pitch for the past three years. Also of significant concern are the high levels of LER observed in EUV resists.

ACKNOWLEDGMENT

The author is greatly indebted to the CXRO MET team including Chris Anderson, Paul Denham, Simi George, Gideon Jones, Lorie-mae Baclea-an, and Nate Smith. This work was funded by SEMATECH and the author thanks Bryan Rice and Stefan Wurm for continued support of the SEMATECH MET exposure facility at the Advanced Light Source. The work was performed at Lawrence Berkeley National Laboratory's Advanced Light Source synchrotron facility and was supported by SEMATECH through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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