Using nanomachining to repair photomasks for the 32nm node and beyond

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Reducing the deflection of atomic force microscope tips makes them more effective and durable for repairing defects in lithographic masks.

The steadily shrinking features in integrated circuits pose ever greater challenges for their production. Compared to the 65nm node, the 45 and 32nm nodes require singular departures in their technical development. One of the most crucial process modules at these smaller technology nodes is lithography. As a result, photomask designers are actively considering every known approach to meet the tight imaging specifications in various process technologies. Reticle-enhancement techniques (RETS) have been used along with future exposure approaches such as double-patterning and extreme-ultraviolet (EUV) technologies. One RET, of particular interest here, is optical proximity correction (OPC), in which subresolution changes to the shape of a feature greatly improve its printability. Smaller, more subtle, and increasingly unavoidable defects in these features can render expensive photomasks, or even an entire mask set, worthless.

Repair of photomask defects is quickly becoming an in-line mask-production and maintenance necessity, and has been pushed to meet or exceed the specifications of future technology nodes. One material-subtractive repair technology in particular that has advanced over the last decade is nanomachining, an application of atomic force microscopy (AFM). Nanomachining removes mask material, such as opaque defects, with no chemical residuals and unsurpassed depth control. Past technical challenges included poor repair-sidewall angles and poor shape definition in extremely small, high-aspect-ratio patterns. Recent nanomachining technology developments have significantly reduced these problems for even the smallest features tested.

At RAVE, we have developed improved processes, designated VIPR™ and COBRA™, that increase repair quality by minimizing elastic deflection of the NanoBit™ AFM tip. This deflection results from forces applied to the tip by the mechanical resistance of the mask materials to nanomachining removal. Improvements were achieved by redirecting forces in directions where the tip is stiffest and by modifying the process so that the removal area is self-aligning, among other refinements.

In practice, the VIPR repair process is optimal for the repair of defects in line and space patterns, using asymmetric NanoBit tips. In addition to such line/space defects, the COBRA process excels in the repair of general, three-dimensional shapes, such as missing contact holes, scatter bars, and corner OPC, with either asymmetric- or symmetric-shaped NanoBit tips. Because of this more general usefulness, the COBRA process is being applied more often at the critical technology nodes, and has been successfully applied to all potential mask materials (quartz, chrome,
Figure 2. Early comparison test of the VIPR (top), and COBRA (bottom) photomask-repair processes. Square missing contact holes were 300nm wide × 300nm long × 150nm deep, and all sidewall angles were >80°.

Figure 3. Repairs of 32nm-node EUV full-height right-edge line/space (left), and missing square contact hole (right) performed with the COBRA process. All sidewall angles were >80° and final depths were within 3–4 nm of target.

MoSi, and EUV multilayer materials). Along with improvements in mask-particle-removal technologies, such as enhanced cryogenic clean, AFM local,1,2 and wet clean, both of these processes have met repair requirements for the 32nm node.

In addition to extending the capability of current production NanoBit tips, these processes also allow for the use of even higher-aspect-ratio Nanobit tips, which are now in development. Although higher-aspect-ratio tips allow for better penetration into higher-aspect features and shapes, the constant strength and stiffness of the tip apex material means that they are significantly more prone to elastic deflection, if not complete breakage, during nanomachining. By reducing overall tip stress, the COBRA and VIPR advanced repair processes allow these tips to be used with lower tip wear. The COBRA process also allows for faster repair of larger defects, thus reducing any potential tool drift and further improving repair quality.

In conclusion, the application of the COBRA and VIPR advanced technologies (implemented exclusively in the RAVE nm450 platform) to nanomachining defect repair permit improved final shape and sidewall angle down to the 32nm lithography process node. These processes also allow for improved repair reliability and lower system cost of ownership by decreasing tip wear and improving ongoing repair development for future nodes.

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References

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