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Since the mid-seventies, when metal-oxide-semiconductor (MOS) circuitry replaced bipolar circuitry for nearly all integrated circuits, shrinking lateral dimensions through the use of continuously improving lithographic technology became the route to keeping Moore's Law valid. By the mid-nineties this route had become increasingly difficult as minimum features of 200 nm approached the so-called 'Rayleigh limit' (although Rayleigh himself used the term 'criterion') and alternatives to ultra-violet optical lithography were being expensively developed. Consequently when Chou and his co-workers, then at the University of Minnesota published their classic papers [1, 2] on 'Nanoimprint Lithography (NIL)' it was clear that this demonstration of 10 nm features size and virtually unlimited throughput represented an extraordinary advance in patterning technology. The technique used was a modification of the manufacturing process for compact disks and involved a heating step and a compressible layer to act as a resist and was similar to a molding process developed in NTT Laboratories in Japan in the seventies [3]. Different from the 'soft lithography' technique which used an elastomer stamp to contact print a self-assembled monolayer (SAM) of ink on a substrate [4], NIL used a hard mold to deform a resist and achieved higher resolution. Others had also been looking at imprint processes. In Europe, Verheijen et al. at the Philips Research Laboratories developed a 'Mold Lithography' [5], in which nanoscale patterns on a mold was duplicated to a layer of UV-curable monomer through the photopolymerization process at room temperature. In the U.S. Willson and his colleagues at the University of Texas at Austin, soon described a technique 'Step and Flash' [6] that also uses UV-crosslinkable materials as resists. The advantages of the UVcurable approach are: 1) needing no heating step, and 2) employing a liquid 'resist' layer which solidified on exposing to UV light; both features facilitate accurate overlay. Others adapted this technique now generally termed 'UV-NIL'.

Despite the excitement generated by this early work the semiconductor industry remained skeptical. Optical lithography continued to improve (past the 'Rayleigh limit') and this industry had recently spent an enormous sum of money (more than a billion U.S. dollars) developing X-ray lithography which failed for a number of reasons but the mask technology was blamed. The fact that the masks were 1x (meaning masks have the same feature sizes as the circuits printed) was singled out rather than the more obvious flaw that they comprised a thick absorber on a thin membrane substrate.

NIL suffered not only from having to use a 1x mask (also known as 'template' or 'mold') but also because it was a contact process. Contact optical printing had been abandoned many decades earlier because of the defects generated by the process.

A less publicized technical challenge is the 'residual layer'. After creating the relief structure in the 'resist', there usually remains in the nominally clear areas a residual layer on the surface of the workpiece that takes an extra etching step, which increases the fabrication cost and can affect the feature size. By controlling the surface chemistry, imprint without leaving a residual layer has been achieved [7]. The mold separation might cause structure distortion, but with the invention of water soluble imprint molds using PVA (polyvinyl alcohol), the mold can be dissolved without separation [8].

Regardless of these disadvantages several companies were founded, both in the U.S. and elsewhere, to sell NIL tools and technology. The initial applications were those that could tolerate some defects and did not require very accurate overlay; bit-patterned (magnetic recording) media (BPM) was the foremost application. However BPM now seems to be fading in popularity for the next generation of hard disk technology because of the development of heat assisted magnetic recoding (HAMR).

For the longer haul some companies (e.g. Molecular Imprints, Canon, Samsung and Toshiba) have been developing NIL for some semiconductor applications such as displays and memory. Overlay errors are now below 10 nm (and in the laboratory have been below 1 nm) and defect densities have been demonstrated to be approaching 1/cm² [9]. In one sense some of us believe that today's situation is similar to that in the mid-nineties as over the last decade the semiconductor industry has been spending billions of U.S. dollars on developing 'Extreme Ultra Violet Lithography (EUVL)' and it still is not economically attractive. So NIL might still emerge as a viable alternative.

Another factor that augurs well for the future of NIL is that other applications such as sensors (particularly biomedical sensors) and miniature actuators are becoming a large enough market to support the development of NIL tools and technology. These applications have benefited from the CMOS scaling race, and the device structures are usually not as complicated as CMOS circuits so that NIL can be a better choice.

Recently NIL is moving roll to roll (R2R). By wrapping a flexible mold around a web and a flexible substrate on another, R2R imprint makes the patterning process continuous and hence significantly improves the throughput. The use of plastic material as the molds also lowers the cost. On the other hand, due to the relatively low Young's modulus of the flexible molds the critical dimension is not as small as that from NIL with a hard mold. The demonstrated resolution (half-pitch) for R2R imprint is ~ 50 nm [10], enough for a wide variety of applications though. To address the alignment between each layer, a self-aligned imprint lithography (SAIL) has been demonstrated for electronic circuits on flexible substrates [11]. The R2R imprint technique employs NIL from lab to fab, and enables the production of a large quantity of electronics including disposable biomedical sensors. Still at its infancy stage, the online metrology, and the process integration with thin film deposition and etching continued to be developed and/or optimized.

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