Strategies for low cost imprint molds

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ABSTRACT

The Cost of ownership (COO) due to the mold can be minimized by first creating the smallest possible original. The cost of this original can be reduced by using the lowest possible resolution pattern generator. If the pattern is regular, then analog pattern generation such as interferometry can be used. The small original is then copied to cover the area by either Step and Repeat or Tiling. Finally multiple working copies are made in a tooling tree for production imprint. The cost and life of the working copies depends on the imprint technology.

1.0 INTRODUCTION

All lithography processes have to deal with the high cost of making the original mask or mold. In production advanced S&R optical lithography, mask making costs dominate the cost of implementing ASIC or short production run devices. Imprint has been targeted as a low cost manufacturing technique for sub 100 nm features and for patterning of functional layers with much larger features. It does not help to have a low cost manufacturing process if the mold making costs are overwhelming. In the research phase, the cost of originating the mold is the problem. In production, the cost of the working copies dominates. Cost of ownership (COO) due to the mold has a target of $1 as part of a total COO of approximately $10 per wafer layer.

The strategy for fabrication of low cost molds is as follows;

- Match origination tool to resolution
- Create the 3D structure directly.
- Minimize origination write time – Step and Repeat to cover larger area
- Minimize cost of working plates using a “tooling tree”. The process life is linked to the conformality and material of the mold.
- Match supply chain to user

2.0 Origination

The first step is to create an original from some data source or by an analog process. The most flexible are the systems that can take random data and produce any pattern – “serial pattern generators” as shown in Figure1..

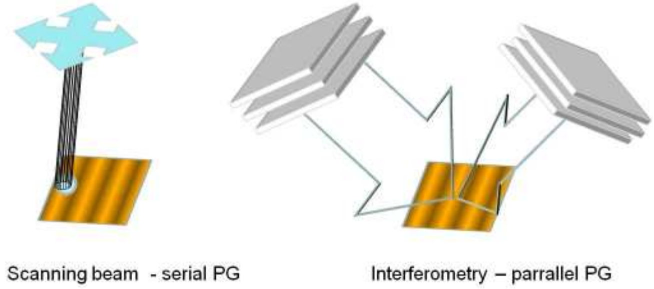


Figure 1 Serial and Parallel Pattern Generation

For large features, ink jet printers are used to print opaque patterns on a transparency and are the ultimate low cost pattern generation tool. The opaque mask is printed into a resist coated wafer using a proximity printer, and create a trench pattern.

Smaller features (<50um), scanning laser and electron beam tools are the backbone of the commercial mask making industry[1]. There are a variety of tools for different feature and substrate sizes up to 1 metergy on a side. As the feature size goes down, the write time and or / the cost of the machine increases. The smallest features that are commercially available continue to shrink in line with the ITRS road map. Features smaller than the road map are only available over smaller areas and are much more expensive and are only available from the companies connected to research institutions[2].

Regular repeating patterns can be created by analog techniques. Arrays of gratings, holes and pillars are easily created by interferometry, and are available from captive, research, and commercial facilities[2]. Very large interferograms (1m x 1m) have been created by captive roll to roll manufacturers[3]. Self assembly using block copolymers have been the subject of research papers[4] but have a problem maintaining order over several microns. Frequency doubling can also be used to create smaller regular features[5].

A typical commercial mask house can deliver a S&R mold for $20K -$60K depending on pattern density. Provided the final production run requires more than 100K substrates, an origination cost of up to $75K can be supported. The different options are summarized in Figure 2.

Random layout	Feature size	3D creation
Ink jet	> 50 um	Optical litho into resist
Diamond turning	> 20 um	Direct
Scanning laser	> 0.3um	Direct into resist or etch
Scanning e-beam	>0.3 um	Direct into resist or etch
Regular (symmetric) layout		
Optical interferometry	> 150 um	Direct into resist or etch
X ray interferometry		Direct into resist or etch
Self assembly - Block polymers	0.05 - 0.2 um	Etch

Figure 2 Origination options

3.0 3D creation

Imprint replicates the 3D texture on the surface of the mold. The most direct way to create the 3D texture uses diamond turning[6] which is limited in feature size but can directly create any 3D shape. It is used for commercial high volume micro-lens array's, Fresnel lenses, and prism films by companies like 3M. Some examples of diamond turned features are shown in Figure 3.

All the techniques in Figure 2, except diamond turning, produce a pattern in resist. The simplest and lowest cost approach is to make a copy of the resist surface (replica) in an imprint robust material, such as Nickel, PDMS or a Sol Gel material as shown in Figure 4a. The original is destroyed in the process. Groups have even used Silicon containing materials as resists to fabricate the mold directly in the resist[7].

The most common approach is to etch into the substrate using the resist as a etch mask[8] also shown in Figure 4a. The mask shops[1] support etching into glass as it is required in the creation of "phase masks".

Conventional resist and etch produces a close to square wave cross-section. More complicated surfaces can be formed by grey scale lithography Figure 4b. In grey scale lithography, the pattern is written with varying dose.

When the resist process has a low contrast of 1.0, the varying dose produces a difference in resist height. Grey scale optical[9] (Figure 5a) and electron beam lithography[10] have both been demonstrated.

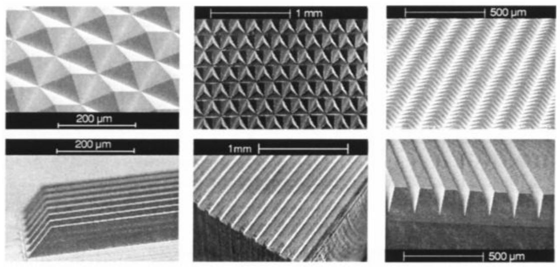


Figure 3 Examples of diamond turned features[6]

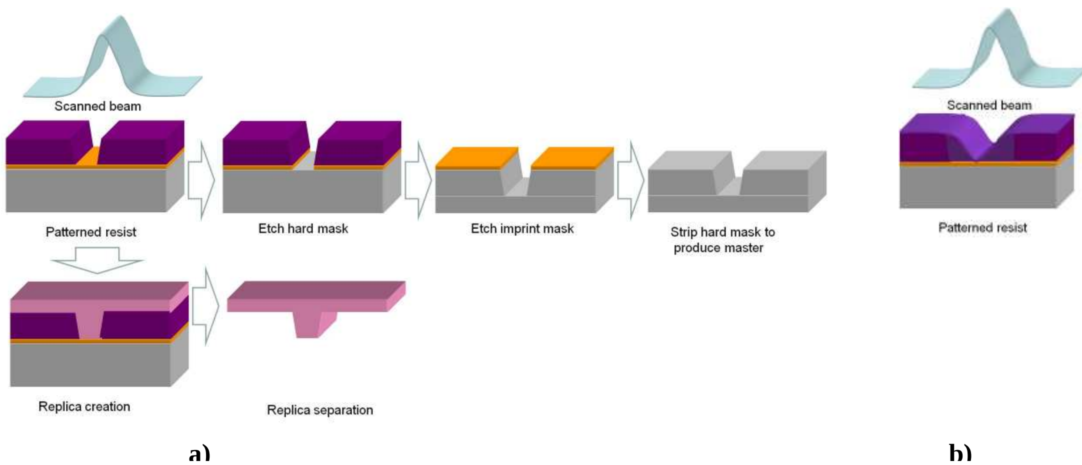


Figure 4 3D creation by a) lithography and etch or replication, and b) grey scale lithography

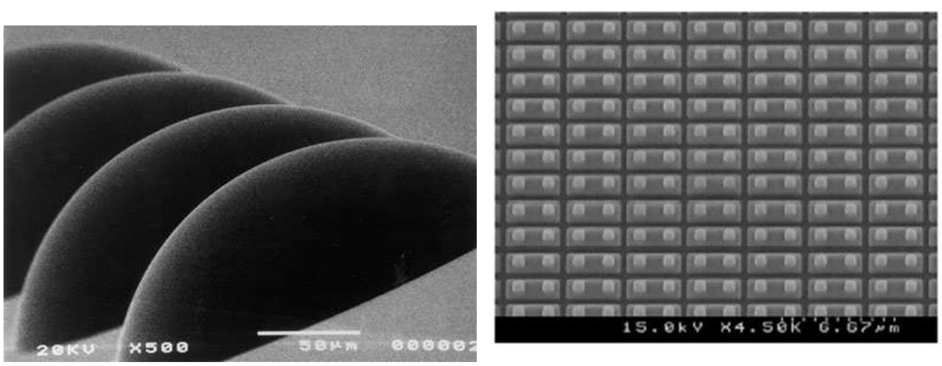


Figure 5 Examples of 3D creation a) grey scale [9] and b) 2 layer mold for metal interconnect[11]

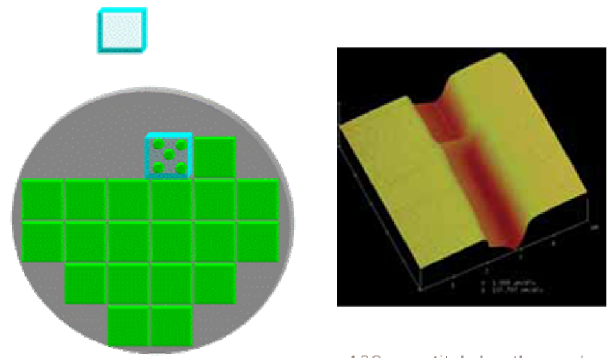
Multilayer processing has been used to create very complex patterns including 2 layer metal interconnect elements[11] (Figure 5b). Other creative solutions have included combining multiple different patterning techniques on one mold[12] (Figure 5a).

4.0 Minimize write time

Write time or area are the biggest factor in cost, so the best way to reduce cost is to make a small area original and then make multiple copies to cover a larger area. Step and Repeat (S&R) imprint lithography has been used to create large area molds. Optical S&R is commercially available at several foundries[13].

The roll to roll manufacturers have been using a similar tiling process. Typically they fabricate multiple Nickel copies (“replicates”) of the original and mechanically assemble (“tile”) them to cover a large area.

The biggest limitation to S&R or tiling is in the lines between steps/tiles (“stitches”). In cases where the end device is equal or smaller than the original, the stitches are not a problem. The creation of larger “seamless stitching” is



100 nm stitch by thermal Imprint - VTT /SET

Figure 6 a) Schematic of S&R, b) example of 100 nm stitch by thermal imprint[14]

much more challenging, and has been the subject of research over the years[14]. A seam is much easier to hide in a complex pattern with plenty of visual detail.

5.0 Minimize working copy cost

Imprinting is a contact process so that the molds have a finite life mostly due to particles on the substrate either damaging the mold or plugging the pattern. If the mold can be cleaned, then the mold can be recycled, although there is potential for erosion of the mold with multiple cleans. The net result is that multiple working copies of the full size original are needed. The number of copies depends on the material of the mold. In turn, the mold material depends on the conformal characteristics of the mold.

In imprint, the mold needs to conform to substrate, because neither is perfectly flat illustrated in Figure 7.

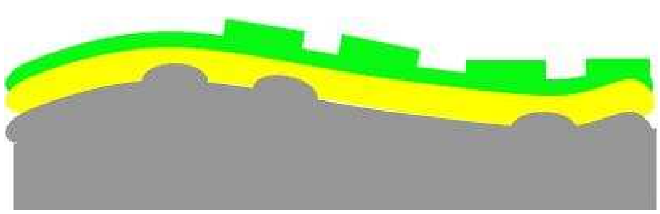


Figure 7 Schematic of a conformal imprint over a non-flat substrate

If the imprint force is around 1 atmosphere or larger, a standard 0.5 mm thick silicon wafer will conform to the mold. Contact printers, vacuum imprinters[15], and capillary driven imprinters[16] all use the wafer as the conformal element against thick glass molds. There are large area imprinters that use a glass wafer as a conformal mold[17]. Glass or silicon wafer molds are readily cleanable in highly oxidizing mixtures such as sulfuric acid / hydrogen peroxide mixtures. Glass mold life of 2000 imprints between cleans and 20-30 cleans have been reported[18]. Flexible large area imprinters can be used to make copies of molds as well as imprint substrates. A mold made by imprint copying an original and then etching would have an incremental internal cost of $20. An external vendor would probably charge several thousand dollars for a low volume process run.

Softer mold surfaces have been used that conform more easily, but they have shorter life and must be cheap to fabricate. The best known are Nickel replicates[19] and PDMS stamps[20], although any polymer that can release from the imprint can be used[21]. The costs of commercial Ni replicas are typically a few thousand dollars. PDMS replicas have to be made by the user, the internal cost is probably $10 for a low volume custom process.

The ultimate short life mold is a "one use" polymer film. Obducat build the one use film in to an integrated automatic imprinter called the "Sindre"[22]. Transfer Devices[23] sell a PVA film that can be used to imprint and then be dissolved away. The material costs of one use molds for the Obducat tool have been reported as $0.5.

			Process life
Hard cleanable surface			
	Etched glass		2000 between cleans
			20-30 cleans
Uncleanable surface - impervious to imprint material			
	Plating - Nickel		2000
	UV / Thermal imprint		
		Si polymer	500-1000
		Epoxy	500-1000
		Resists	200-500
	Cast - PDMS 1 or 2 layer		< 100
Soft material			
	PVA		1
	Obducat		1

Figure 8 Summary of process life for imprint mold materials

In order to create enough copies, a tooling tree is used. If the process life is N, then every copy of the original can be used to make N more copies. If the production run length is P and the number of generations is L, then $P = N^L$, and $L = \log(P)/\log(N)$. A 1M run with a 100 imprint process life mold requires 3 generations.

All of the working plate solutions discussed above have an incremental cost per substrate of much less than $1 a substrate.

6.0 Supply chain

From a commercial stand point, using industry stand supply chain is a huge advantage in terms of total costs. They are willing to pay higher prices if the infrastructure and quality control is available. Research houses tend to rely on creative "home made" origination as the only way to evaluate different designs within research budgets.

7.0 Conclusions

The focus of researchers should be on finding ways to make molds directly from resist patterns by some form of replication. This should then be expanded by S&R to cover the target area.

The focus of commercial operations should be on establishing either a vendor or internal supply of low cost working plates at the same time as establishing the substrate imprint process.

[1] Suppliers such as DNP, Photronics, Toppan

[2] NILT based in Denmark, (www.nilt.de)

[3] Wavefront Technology, based in California www.wavefront.com

[4] P. Deshpande et.al. , "Large area orientation of microphase separation in 21 nm period diblock copolymer gratings", NNT 2003

[5] Z. Yu et.al. "Fabrication of 30 nm pitch nanowire array imprint molds by frequency doubling for ultra high density molecular electronics", NNT 2005

[6] Moore Machine tool (www.moore.com)

[7] M. Kawamori et.al. "Nanoimprint lithography using hydrogen silsequioxane (HSQ) mold", NNT 2005

[8] Miller et. al. "Step and flash imprint processes and technology of photonic crystal patterning : Template Replication through wafer processing. NNT 2007

[9]www.RPCphotonics.com

[10] K. Mohamed et. al. " The fabrication of 3D molds for UV curable nanoimprint by using the variable dose controlled exposure of electron beam" NNT 2006.

[11] G. Willson et.al. "Imprint Lithography for Dual Damascene" NNT 2006

[12] J. Ahopelto, "Progress of NaPa", NNT 2005

[13] Silicon Valley Technology Center – www.svtc.com

[14] G.Lecarpentier et.al. "Step and Stamp Lithography for stitching patterns in large stamp manufacturing" NNT 2007

[15] Nanonex, EVG, Suss for example

[16] MII (www.militho.com)

[17] M. Watts et.al. "S-FIL based large area imprint solutions for non flat substrates" NNT 2005

[18] S.V. Shreenivasan et.al, SPIE Microlithography , March 2008

[19] Technotrans (www.technotrans.com) and other captive roll to, roll suppliers

[20] Heptagon (www.heptagon.fi)

[21] I.Bergmair et al, "Replication of stamps for UV-NIL using Ormocers", NNT 2007

[22] Obducat (www.obducat.com)

[23] Transfer Devices (www.transferdevices.com)