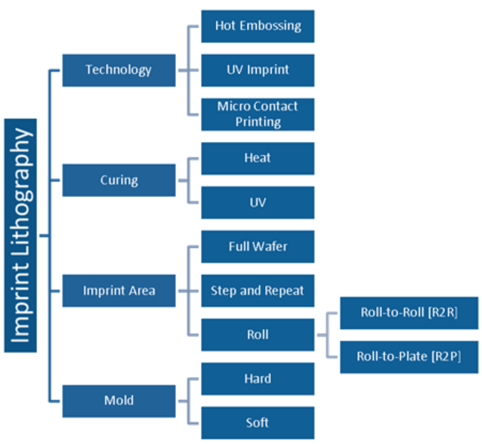
EVG Micro and Nanostructure Manufacturing Guidelines using Imprint Techniques:

Introduction:

Nanoimprint lithography (NIL) is a novel method for the fabrication of micro/nanometer scale patterns with low cost, high throughput and high resolution. Unlike traditionally optical lithographic approaches, which create pattern through the use of photons or electrons to modify the chemical and physical properties of the resist, NIL relies on direct mechanical deformation of the resist and can therefore achieve resolutions beyond the limitations set by light diffraction or beam scattering that are encountered in conventional lithographic techniques. NIL is based on the principle of mechanical deformation of a thin polymer film (mechanical deformation of the resist) using a template (mold, stamp) containing the micro/ nano-pattern, in a thermo-mechanical or UV-curing process. In other words, NIL uses the direct contact between the mold (template) and the thermoplastic or UV-curable resist to imprint (or replicate) the pattern. The switch from using light to contact to pattern brings some advantages. For instance, it can achieve resolutions beyond the limitations set by light diffraction or beam scattering that are encountered in conventional techniques, simplifying process and equipment conditions and largely reduces cost. However, direct contact will indeed bring new challenges and issues, the most important of which are defect density, alignment and production reliability. Since NIL can be considered as a process based on squeeze flow of a stacked viscoelastic material between a mold and a substrate, the property of surface condition between the two materials has to be considered throughout the entire process, both from topographical, chemical, and mechanical points of view. Furthermore, characteristics such as adhesion, surface energy, surface area, etc. of the interface have a great impact on the separation capability, filling behavior which can strongly influenced pattern quality, automation and throughput. The patterned polymer can either act as a functional device layer, e.g. lenses for imaging sensors, micro fluidic chip, biomedical array etc, or as a high resolution mask for subsequent steps of the process (metal deposition, electroplating, etching and lift-off process). NIL has demonstrated its capabilities in numerous applications like in electronics (e.g., hybrid plastic electronics, organic electronics and photonics, nanoelectronic devices in Si and in GaAs), in photonics (e.g., organic lasers, high resolution organic light-emitting diode (OLED) pixels, diffractive optical elements, broadband polarizers), in magnetic devices (e.g., single-domain magnetic structures, high-density patterned magnetic media and high capacity disks), in nanoscale control of polymer crystallization and in biological applications (e.g., manipulating DNA in nanofluidic channels, nanoscale protein patterning, the effect of imprinted nanostructures on cell culture, nanopore sequencing or cellomics. The particular advantage of NIL compared to other lithography techniques and next generation lithography is the ability to fabricate large-area and complex three dimensional (3D) micro/nanostructures with low cost and high throughput.

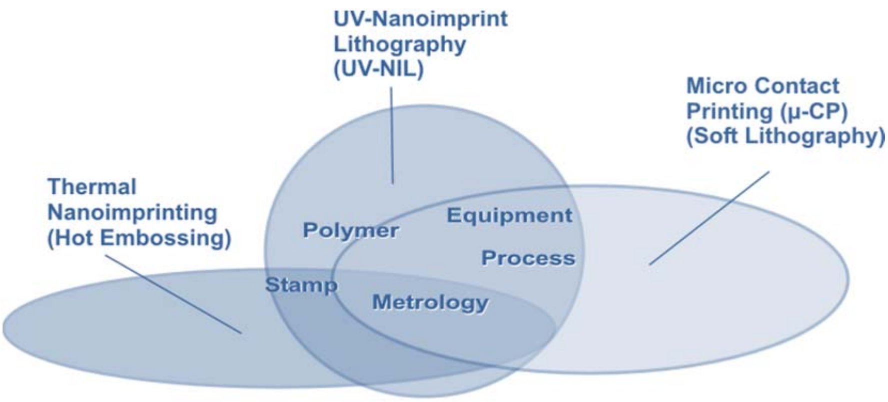
Classification of imprint lithography:

Nanoimprint lithography (NIL) is mainly differentiated in hot embossing, UVlithography with hard or soft molds and micro contact printing. SiO_2, Ni, Si, Si_3N_4, SiC molds are usually used for hard nanoimprint lithography. Polymer materials, such as PDMS, PMMA, PUA, PVA, PVC, PTFE, ETFE, are main components for the fabrication of soft molds. Based on the imprint area, the technology is further differentiated into full-wafer nanoimprint lithography, step-and-repeat nanoimprint and Rollto-roll [R2R] or Roll-to-Plate [R2P] nanoimprint lithography. R2R or R2P is especially suited for the mass fabrication of flexible devices. Each classification is afflicted with certain advantages and disadvantages (e.g., resolution, alignment accuracy, choice of materials, throughput, cost of ownership) which has to be considered during device and process design and development. The classification of nanoimprint lithography is indicated in Fig. 1.



In ***hot embossing*** a polymer sheet or a spin-on polymer is heated above its glass transition temperature and imprinted at high contact forces and vacuum. The stamp material depends on the required feature sizes and the involved materials. After reaching the imprint temperature of the polymer the contact force is applied. Its amount is dependent on various parameters such as the stamp area, the type of polymer and the feature geometry. The contact force remains applied until the temperature of the heaters reach the de-embossing temperature. This is the temperature level, which allows a reliable and residual free separation of the stamp from the polymer. In ***UV-based nanoimprint*** lithography a transparent template with nanostructures on its surface is used to deform a thin resist film or an active material deposited on a substrate followed by a hardening step. The film is cured by photo chemical cross-linking before the stamp is released. When polymer chains are linked together by cross-links, they lose some of their ability to move as individual polymer chains. For example, a liquid polymer (where the chains are freely flowing) can be turned into a "solid" or "gel" by cross-linking the chains together. In this way even suspensions of glass are micro and nano patternable and avoid costly vacuum processes such as metallization or etching. UV imprint lithography can be carried out in a single step, full-field imprinting and step-and-repeat approach. Single step imprinting structure an entire wafer (up to 300 mm) or one small area (called a die) at one time, whereas step-and-repeat imprints one die in a hard or soft UV-NIL approach of a wafer at a time and then moves to a new area of the wafer. The fundamental characteristic of ***micro contact printing [µCP]*** is the formation of a contact on the molecular scale between the elastomeric pre inked stamp and the substrate. In a µCP process, inked chemicals are transferred from an elastomeric stamp to a surface to build up a Self Assembling Monolayer (SAM) or to transfer biological/ chemical materials.

The elements besides equipment and processes required for imprint lithography are (i) a stamp with predefined surface relief nanostructures, and (ii) a suitable polymer or resist that can be deformed and hardened to preserve the shape of the structures. In UV-NIL the resist material is applied on top of a substrate. The mold used in NIL can essentially be any type of solid



Synergies of NIL Technologies

General design rules in UV Nanoimprint:

UV Nanoimprint is designed as massive parallel replication process of sacrificial layers or permanent layers. Etch selectivity is comparable to standard semiconductor processes but needs to be adjusted for the underlying bulk material. Using glass in suspension, glass micro and nanostructures without costly vacuum processes such as metallization and etching can be manufactured. Furthermore UV nanoimprint lithography enables the manufacturing of 3D structuers which might reduce the required steps for device manufacturing. In any case the most important aspect in imprint lithography is the master or stamp manufacturing technique. One have to be aware that certain feature like nanoscale 3D structures require unconventional manufacturing techniques.

- Maximum substrate size (length x width) = 300 mm x 300 mm
- Manufacturing throughput: > 60 units per hour
- Maximum substrate thickness = 10mm (Semi Standard)
- Minimum substrate thickness = 0.05 mm on foils; 150 µm on semiconductor materials
- Top to bottom alignment: possible
- Minimum structure size: down to 35 nm for high volume manufacturing
- Maximum structure size: geometry dependent but up to 5 mm in diameter demonstrated
- Maximum aspect ratio: 1:4, for sub µm structures ideally the aspect ratio stays below 1:2

General design rules in Hot Embossing:

Hot embossing is also considered as massive parallel replication process mostly for reshaping bulk thermoplastic materials. Dependent on equipment force and temperature, materials of glass transition temperatures up to 650° on up to 300 mm round substrates can be processed. This would even allow to thermally emboss into certain glasses directly such as Borofloat glass.

- Maximum substrate size (length x width) = 300 mm round
- Manufacturing throughput: equipment dependent
- Maximum substrate thickness = 15 mm (Semi Standard)
- Minimum substrate thickness = 0.100 mm on foils
- Top to bottom alignment: possible
- Minimum structure size: down to 35 nm for high volume manufacturing
- Maximum structure size: geometry dependent but up to several 100 µm
- Maximum aspect ratio: 1:15 (w:h), for sub µm structures ideally the aspect ratio stays below 1:2

Material Examples:

Thermoplastic Materials		
Acronym	Full name	Properties
COC, Topas	Cyclo Olefin Copolymer (COC, Topas)	High transparency, temperature stability 140°C
PP	Polypropylen	Good mechanical properties, temperature stability 110°C
PC	Polycarbonate	High transparency, temperature stability 130°C
PTFE	Polytetrafluorethylen	High chemical and temperature resistivity, temperature stability 260°C
PEEK	Polyetheretherketone	High temmperature resistivity, temperature stability 250°C
PS	Polystyrene	Transparency, temperature stability 80°C
PVDF	Polyvinylideneflouride	Chemical inert, piezo electric, temperature stability 150°C
SU8	SU8 sheets	Negative resist, quick mastering
Others: Borofloat glass, Teflon,		

General design rules in Roll-to-Roll Hot Embossing:

Using rolls instead of plates, roll-to-roll enable continuous molding with significant advantages in operational speed and device throughput. In roll-to-roll hot embossing, a thermoplastic sheet passes between two rotating rollers. The deformation of the thermoplastic material under the pressure and elevated temperature of the mold imprints the structures into the polymer. Roll-to-Roll hot embossing is especially well suited for structuring of micron and especially sub mm structures. Furthermore the technology implies advantages over mainstream reshaping technologies such as injection moulding if structured thin films are required.

- Maximum substrate size (length x width) = 300 mm web width, Continuous mode operation

- Manufacturing throughput: up to 10 m/min structure dependent
- Maximum substrate thickness = 0.5 mm
- Minimum substrate thickness = 0.100 mm
- Minimum structure size: down to 50 nm for high volume manufacturing
- Maximum structure size: geometry dependent but up to several 10 µm
- Maximum aspect ratio: 1:2 (w:h)