Nanoimprinting with NRF’s NIL 6

Obducat NIL 6

- Substrates: pieces to 6 inch, hard or soft
- Thermal cure with PMMA, MR I 7010 etc
- Alignment to about 3 microns
- Temperature to 300 °C
- Pressure 15 to 80 bars
- Resolution < 50 nm possible
- Up to 160 step recipes for precise process control
NIL 6 Purpose

• To transfer exact pattern from a mold or stamp into a substrate

Requirements

• Substrate is a coated wafer (Si, glass, plastic etc) or polymer
• Special coating is a polymer which can be heated above glass transition temperature, stamped and then cooled to hold image
• Coating must be very uniform (< 2 nm), free from particles and bubbles and have same thickness as desired pattern (100-200 nm). For UV Imprint, coating must be photosensitive. Our NIL 6 does not have the UV option at this time
• Stamp or mold must have exact features as desired with both lateral and vertical dimensions. For UV imprint, mold must be transparent
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Thermal Imprint Process

Wafer has a very uniform polymer spun on its surface. A pre-patterned mold (stamp) is positioned on top of the resist to form a stack. (Alternately the wafer itself can be a polymer so that a spin on film is not required.)

The stack is heated above Glass Transition temperature (Tg) up to 300°C to make the resist soft but below liquid temperature.

When the resist is soft, the mold and wafer are pressed together with pressurized gas from 15 to 80 bars. The mold and wafer needs to be pressed together for some time in order for the resist to fill in all the cavities of the mold.
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Thermal Imprint Process

The imprint stack is cooled down to a demold temperature below $T_g$ in order for the resist to solidify. The mold is then removed and the wafer is left with a pattern on top. And a small residual layer in the bottom of each structure.

The residual layer (>15nm) needs to be removed with an O2-plasma.
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Thermal Imprint Process

• A thin residual layer ensures a good etching process.
• The residual layer should be optimized for each mold and resist batch.
• Spin coat a wafer with a resist thickness similar to design depth/height of mold
• Measure the residual layer after imprint and adjust the resist thickness to thicker or thinner depending in result.
• A good residual layer should have an average of >15nm over the whole wafer.
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Thermal Imprint Process

The exposed wafer surface can now be etched with an RIE to the depth desired.

After stripping the resist in an O2 plasma, the mold pattern is now etched into the substrate.
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Process Considerations

• Polymer (PMMA, mrl7010) properties (thermal vs UV)
• Residual layer optimization (for each mold and resist)
  - Spin coat a wafer with a resist thickness similar to design depth/height of mold
  - Measure the residual layer (AFM) after imprint and adjust the resist thickness to thicker or thinner depending in result.
  - A good residual layer should have an average of >15nm over the whole wafer.
  - Measure over a pre-defined area to check for stretching effects
  - All measurements should be compared with measurement results on mold.
• Release layer for mold is needed for clean separation of mold substrate
  - Silanization treatment covers mold surface to form Si-O-Si bond
  - Aminosilanes, Glycidoxy silanes, Mercaptosilanes are possible
  - Low surface energy polmer/plasma treatments
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Problems/Issues

• Insufficient filling
  – If the resist is too shallow, the structures will not be deep/high enough.
  – Too thin of a residual layer can cause insufficient filling.

• Proximity effect
  – Polymer displacement during imprint is uneven and can cause insufficient filling on some areas, and other areas are fine.

• Stretching
  – Structures can stretch or retract due to thermal expansion during heating/cooling process.
  – By editing the imprint process, these stretches can be compensated to some degree.
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Problems/Issues

• Particles
  – Hard imprinting (Hard substrate and hard mold) are very sensitive to particle contamination.
  – Particles cause insufficient filling in a large area around the particle.

• Broken wafers
  – If the loader plate is scratched, hard wafers (Like Si, Qz & InP) will break during imprint.
  – If two wafers are misaligned during imprint (edges sticking out), the edge can be broken during imprint

• Adhesion
  – If the mold is not properly treated, the pattern can be clogged with resist.
  – Mold cleaning is an essential part of imprinting (ultrasonic bath, Aleg 355 etc).
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Problems/Issues

• Air bubbles
  – Substrate needs to be rolled on against mold in order to remove air bubbles.
  – Air bubbles can escape when imprinting into a soft material, but hard materials trap them causing insufficient filling.

• Rip-off effect
  – The resist can be torn from the wafer surface during demolding.
  – This can be caused by unclean wafer surface.
    Acetone + IPA in ultrasonic bath is one suggestion
    RCA1 + RCA2 is another.
  – Overheating is another cause
  – Bad adhesion treatment on mold is also common.