

Mold Fabrication for 3D Dual Damascene Imprinting

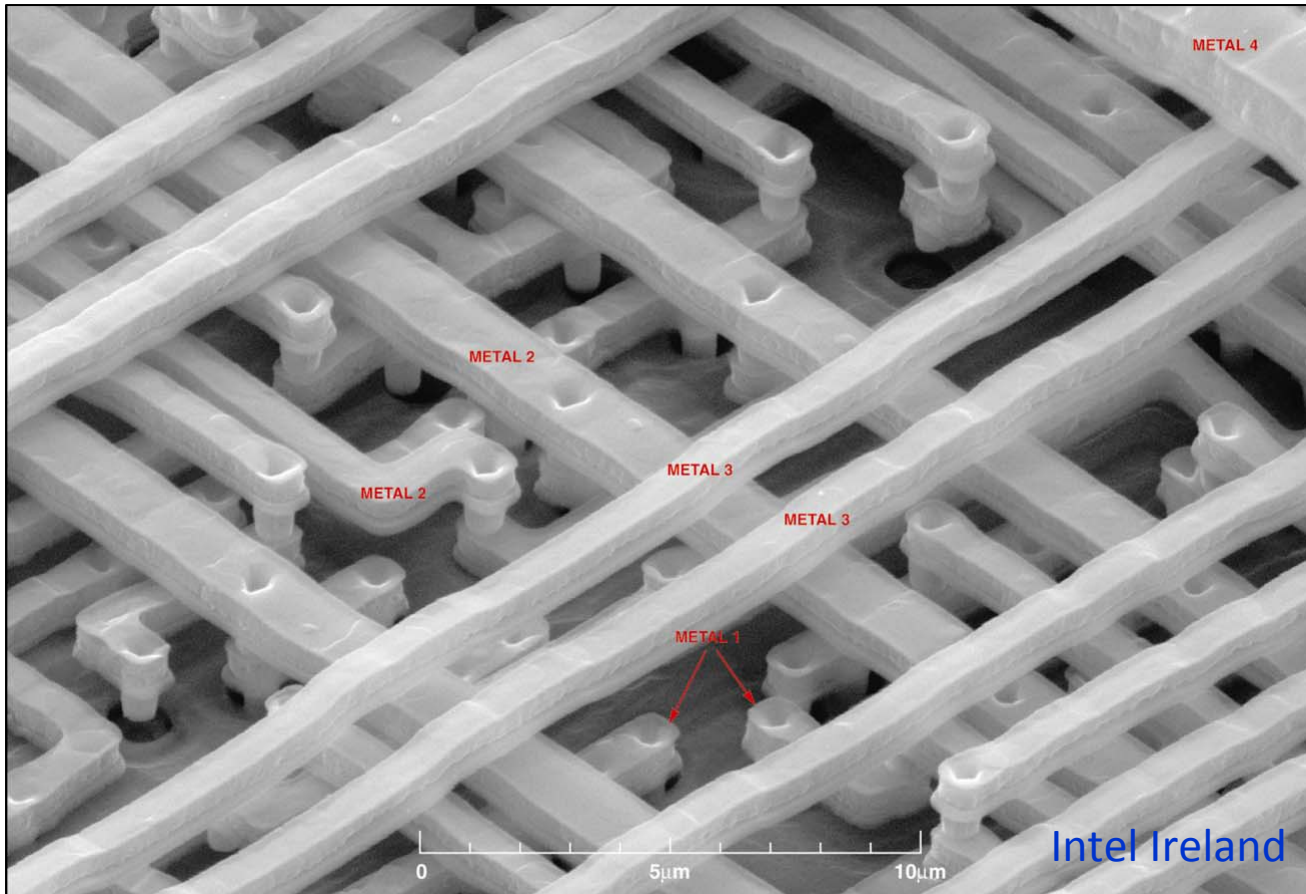
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Outline

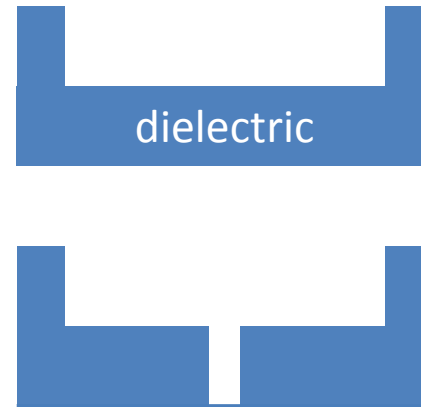
- Introduction to IC metal interconnect fabrication
- Mold fabrication for imprint damascene process
- E-beam resist selection and mold fabrication result
- Summary

IC interconnect: Cu lines and vias

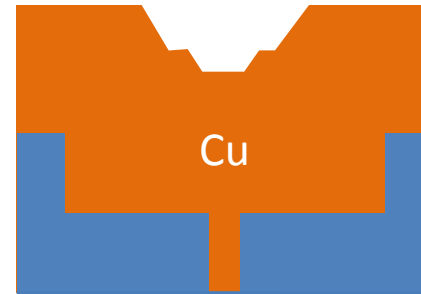


Dual damascene process (overview)

Lithography define the trenches and then the via-holes



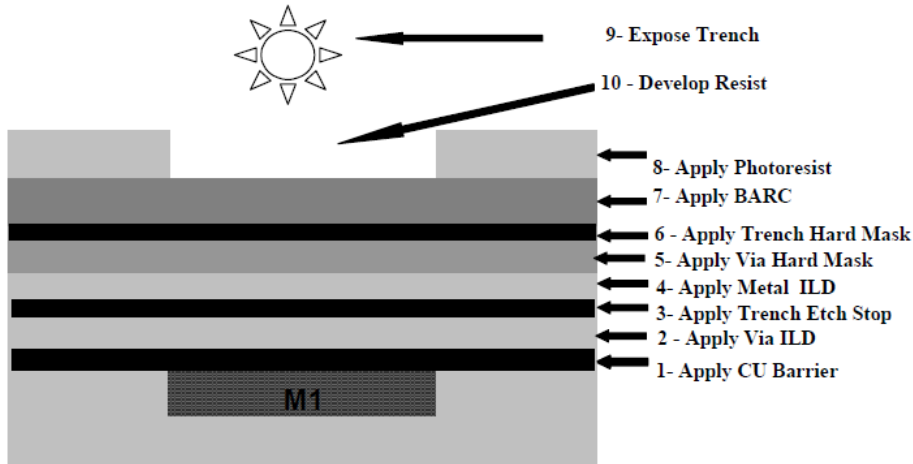
Cu filling by electroplating



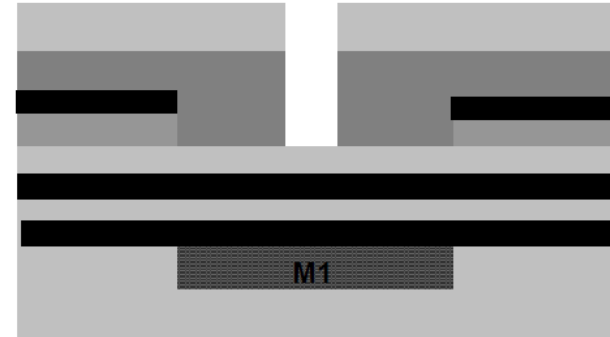
Planarization by chemical mechanical polishing



Dual damascene process (detail)

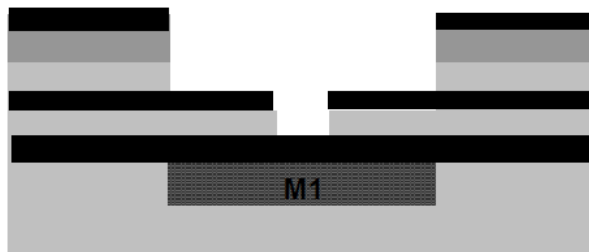


- Step 11 - Etch Through Trench Hard Mask
- Step 12 - Ash Resist
- Step 13 - Apply BARC
- Step 14 - Apply Photoresist
- Step 15 - Expose Via
- Step 16 - Develop Resist
- Step 17 - Etch Via Hard Mask

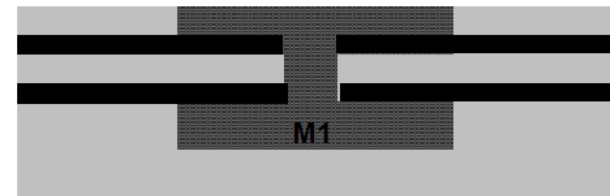


ILD: inter-layer dielectric
CMP: chemical mechanical polishing

- Step 18 - Etch Metal ILD and Trench Stop
- Step 19 - Ash Resist and Via Hard Mask Open
Etch Trench and Via ILDS



- Step 20 - Etch CU Barrier
- Step 21 - Seed CU
- Step 22 - Plate CU
- Step 23 - CMP

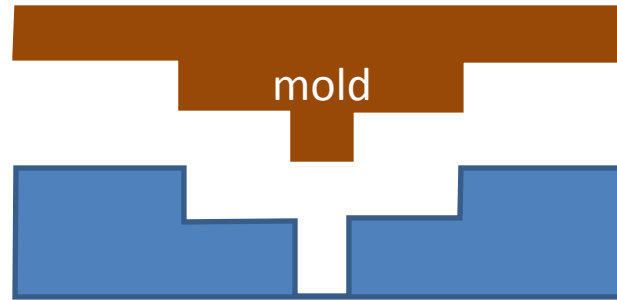


Toppan Photomask Inc. and U. Texas

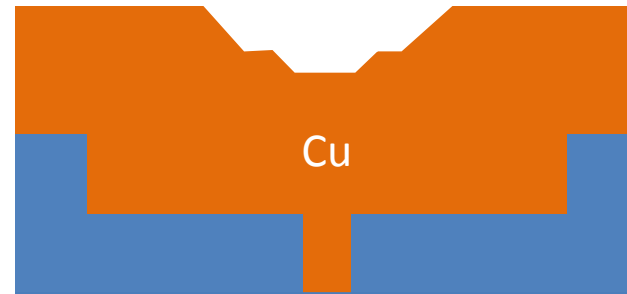
23 steps to connect metal 1 to metal 2

Imprint damascene process (overview)

Imprint



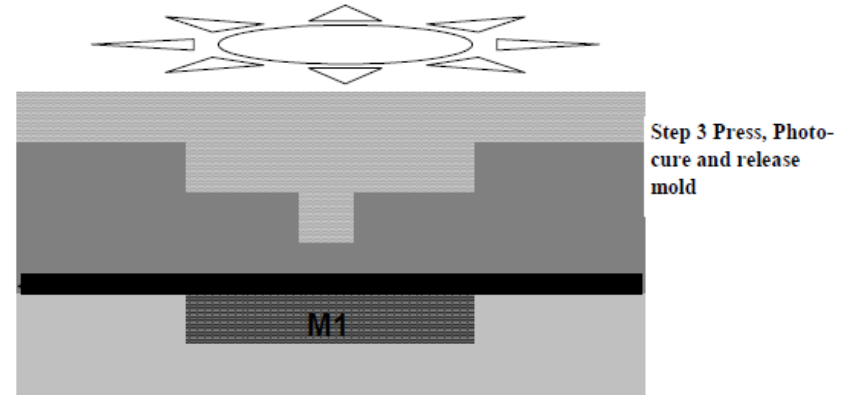
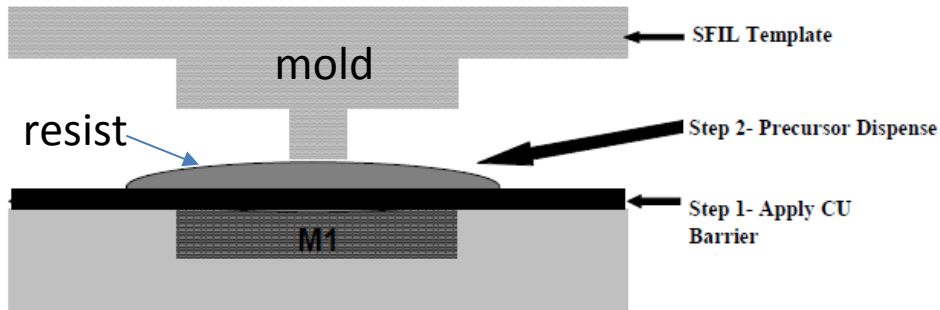
Cu filling



Polishing



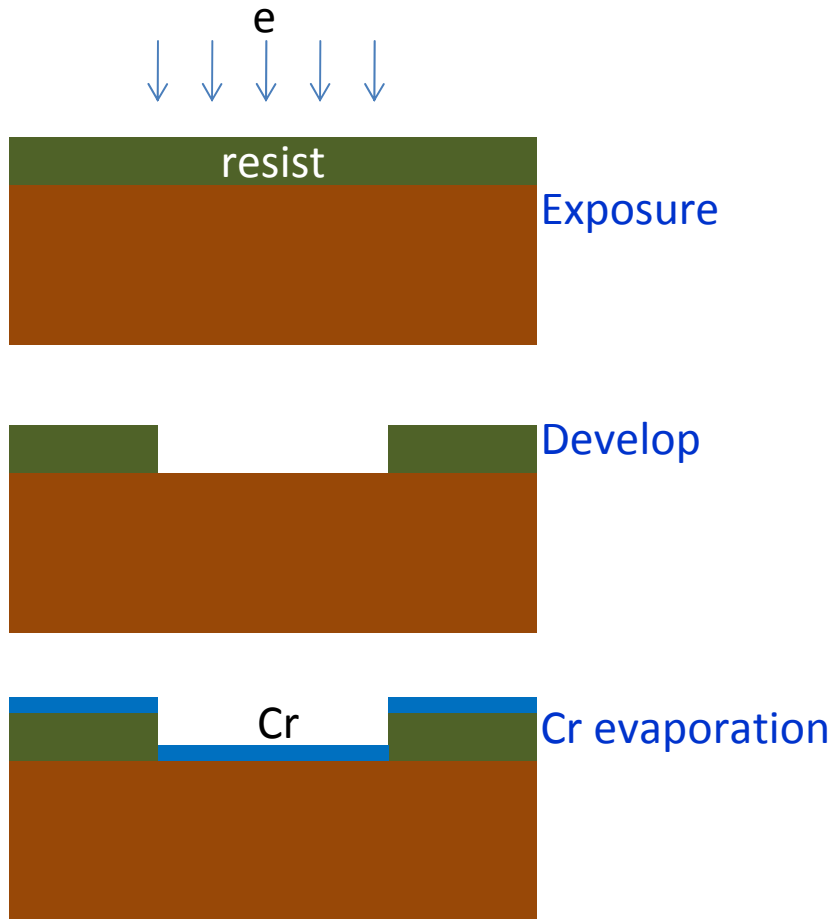
Imprint damascene process (detail)



Toppan Photomask Inc. and U. Texas

8 steps,
as compared to 23 steps using traditional
deep UV lithography

Imprint mold fabrication (by 2× e-beam lithography)



Cr liftoff



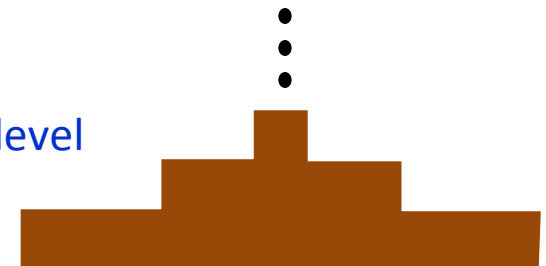
RIE Si
(reactive ion
etching)



Spin on resist

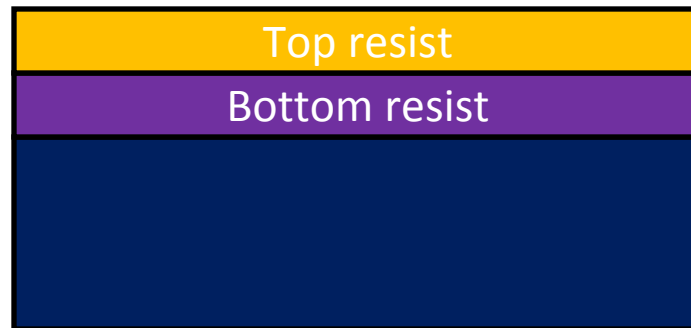
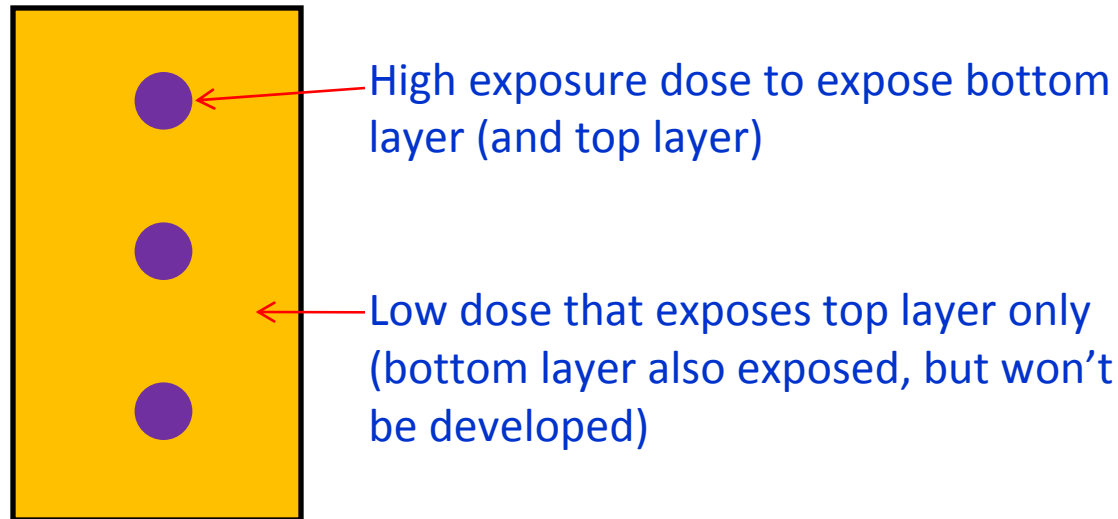


Repeat for via level



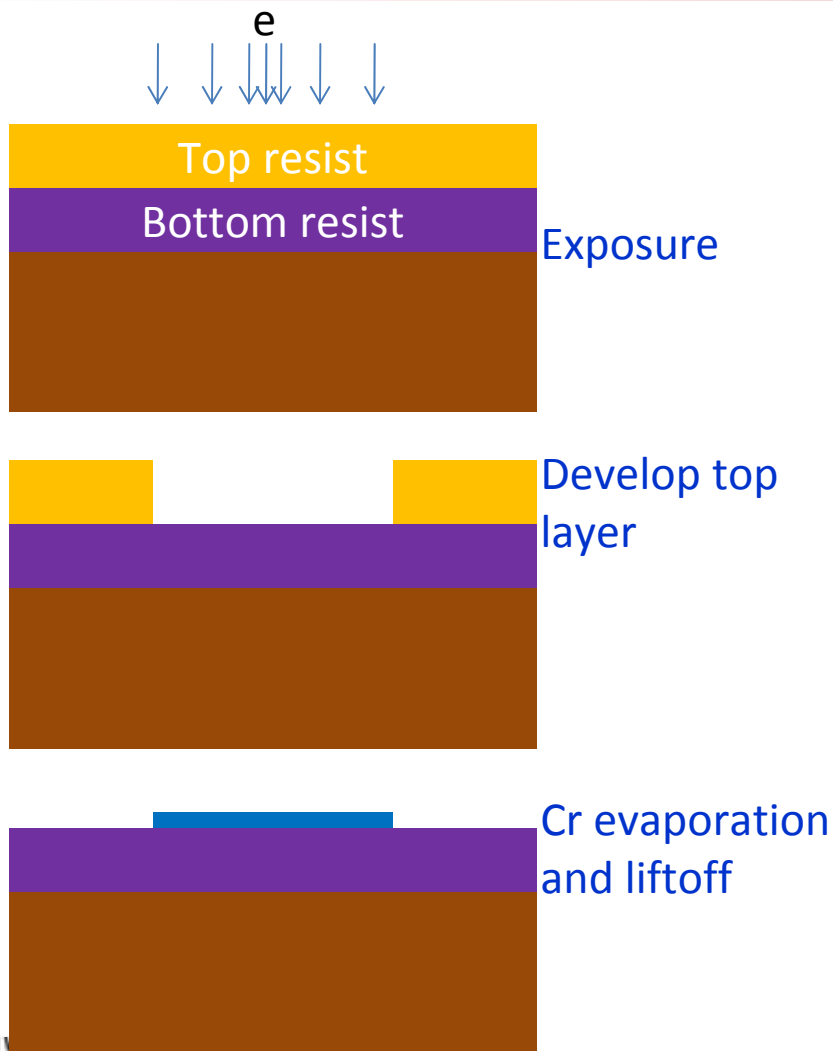
Imprint mold fabrication (by 1× e-beam lithography)

Define the two-level (line and via) patterns within *one* e-beam lithography using *bi-layer* resists, with top layer more sensitive than the bottom one.

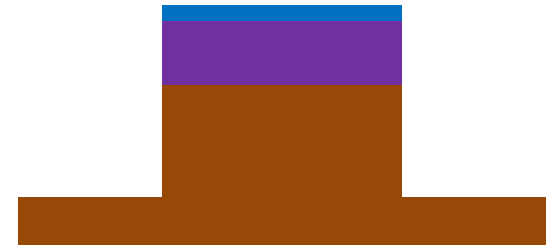


Imprint mold fabrication

(by 1× e-beam lithography, 2× Cr liftoff)



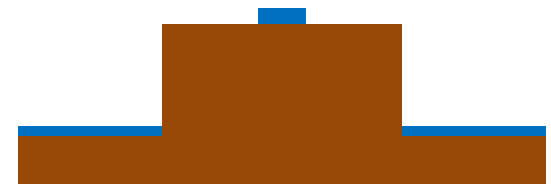
RIE etch
bottom resist
layer and Si



Remove Cr,
develop
bottom layer



Cr liftoff

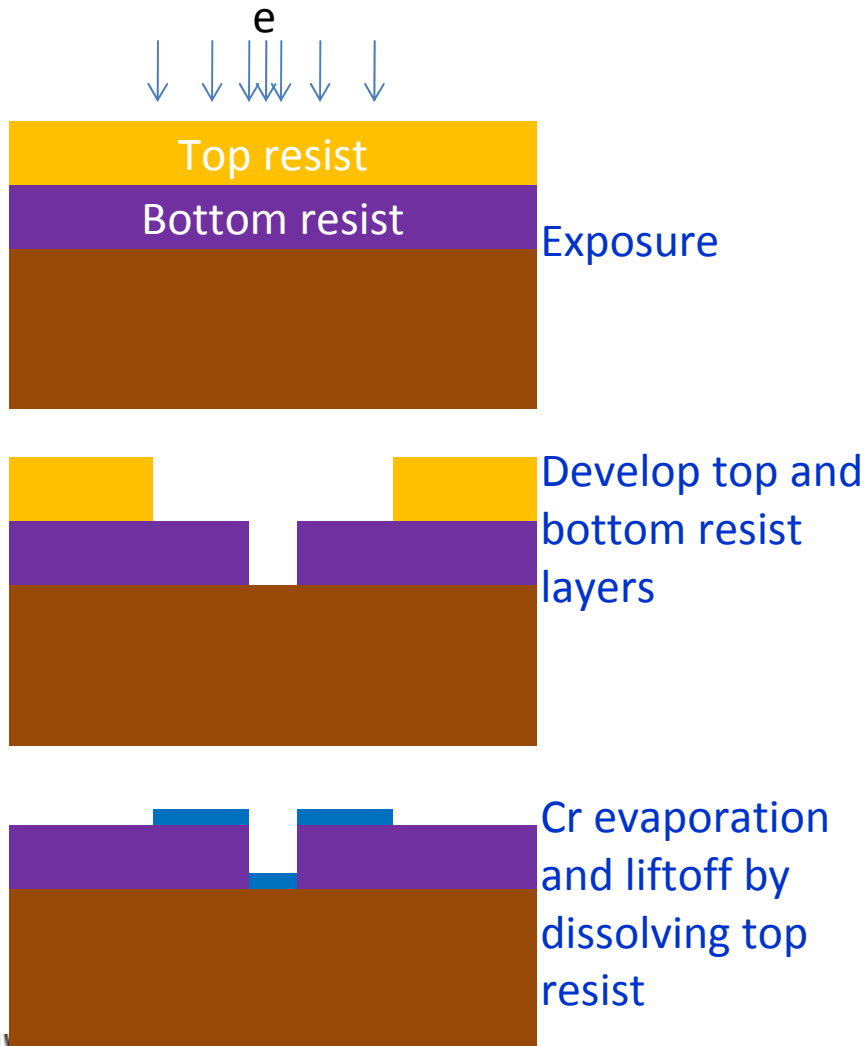


RIE Si and
remove Cr



1× e-beam lithography, 2× metal liftoff, 2× RIE

Imprint mold fabrication (by 1× e-beam lithography, 1× Cr liftoff)



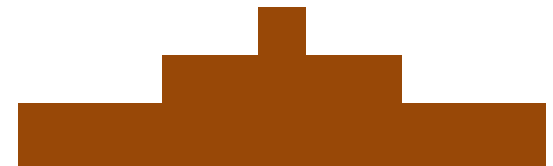
RIE etch
bottom resist
layer and Si



Liftoff Cr by
dissolving
bottom resist



RIE Si and
remove Cr



1× e-beam lithography, 1× metal liftoff, 2× RIE

Resists selection

The bi-layer resist:

1. The bottom layer must have sensitivity much lower than the top layer.
2. Their chemistry must be “orthogonal” to each other: the solvent that dissolves one resist (for spin-coating and liftoff) shouldn’t attack the other resist.

The combination of the two most popular resists PMMA and ZEP, though their sensitivity is very different (ZEP is 3× more sensitive than PMMA), won’t work because they use similar solvents (anisole or chlorobenzene).

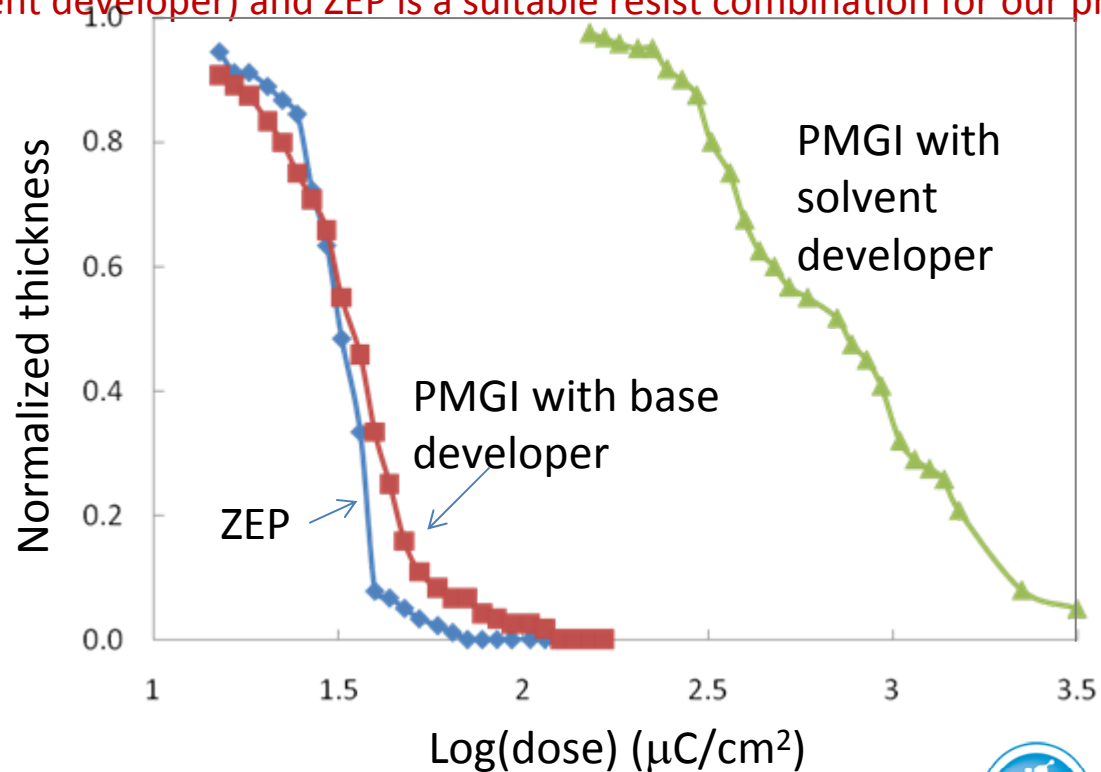
PMGI as an e-beam lithography (EBL) resist

PMGI: poly(dimethylglutarimide), commonly used as a liftoff resist with controllable undercut profile.

Soluble in alkaline solution such as photolithography developer, but not in common solvents.

As EBL resist, its sensitivity is high when using base developer, low when using solvent developer.

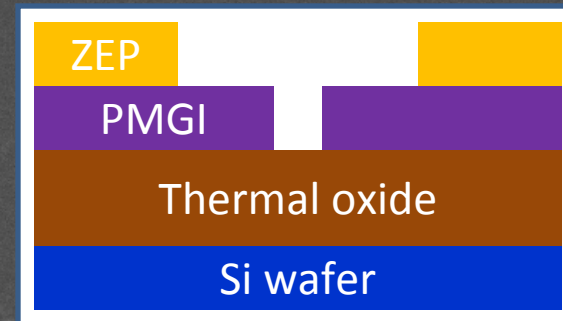
Therefore, PMGI (with solvent developer) and ZEP is a suitable resist combination for our process.



Trench/via-hole in bi-layer resist stack

ZEP-520A 100nm, developed by xylene for 20sec.

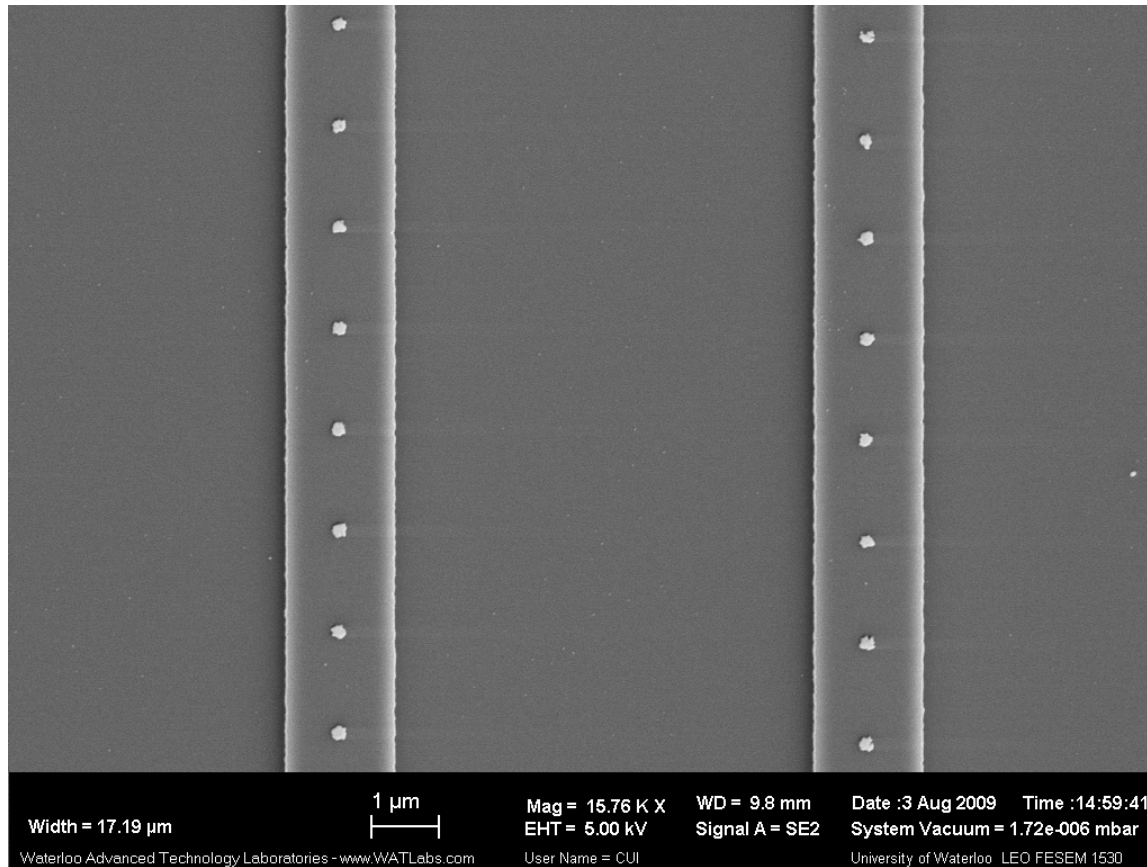
PMGI 80nm, developed by methyl ethyl ketone (MEK) for 10sec.



Holes in PMGI

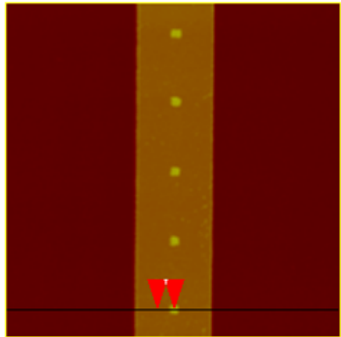
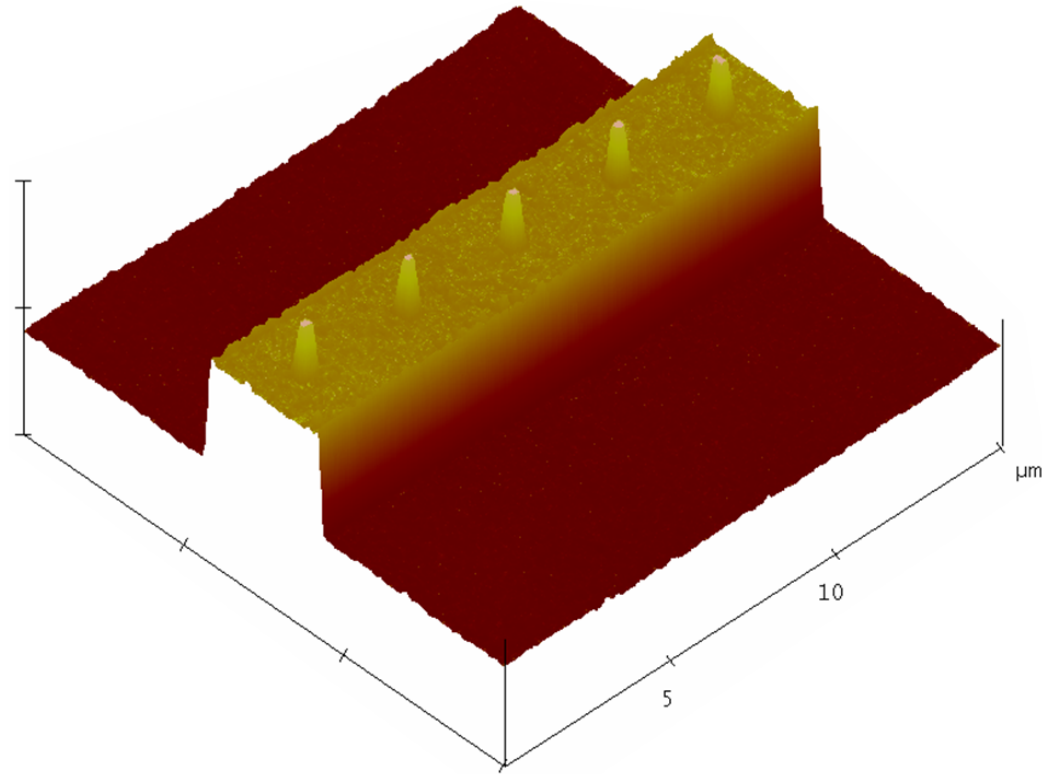
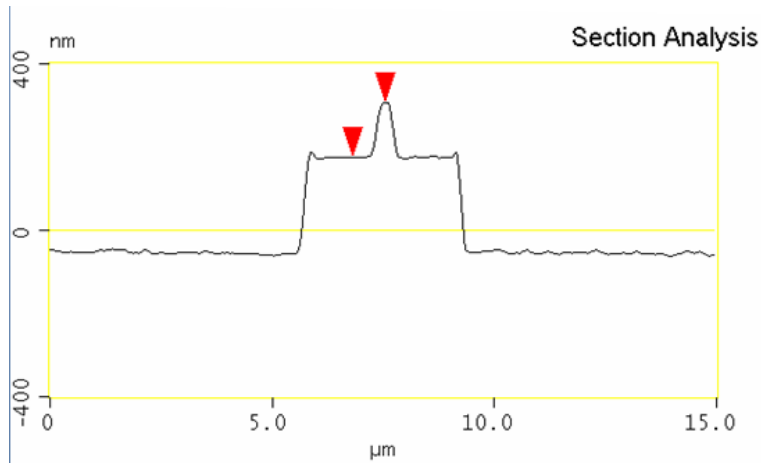
ZEP-520A

Imprint mold for damascene process (SEM)



Ridge width 1.5 μm , pillar diameter 150nm

Imprint mold for damascene process (AFM)



Ridge width 1.5μm, height 230nm
Pillar diameter 150nm, height 130nm

Summary

- IC interconnect is fabricated by dual-damascene process, which consists of 23 steps for each metal level.
- Imprint damascene process reduces the steps to 8.
- The imprint mold has been fabricated by e-beam lithography, with 2× (e-beam lithography + Cr deposition and liftoff + reactive ion etching).
- Our process uses only 1× (e-beam lithography + Cr deposition and liftoff), which is much simpler than previous processes.
- More importantly, in our process the two-level patterns (line and via) are *self-aligned*, with perfect alignment if ignoring noise during e-beam writing.
- We demonstrated the fabrication of imprint mold with 150nm pillars sitting on 1.5μm ridges using PMGI and ZEP resists.