Focal Extension – A Novel Lithography Technique to Enable Fine-Pitch Patterning on High Topography Substrates for FOWLP

Golam Sabbir and Subramanian S. Iyer | UCLA CHIPS
golam.sabbir@ucla.edu | University of California, Los Angeles

Motivation

- Interconnect pitch in fan-out wafer-level packaging (FOWLP) is limited by substrate warpage.
- Greater topography requires a greater depth-of-focus (DOF) of lithography systems (and novel auto-focus methods) for patterning of fine features.
- Commercially available steppers have limited depth-of-focus.

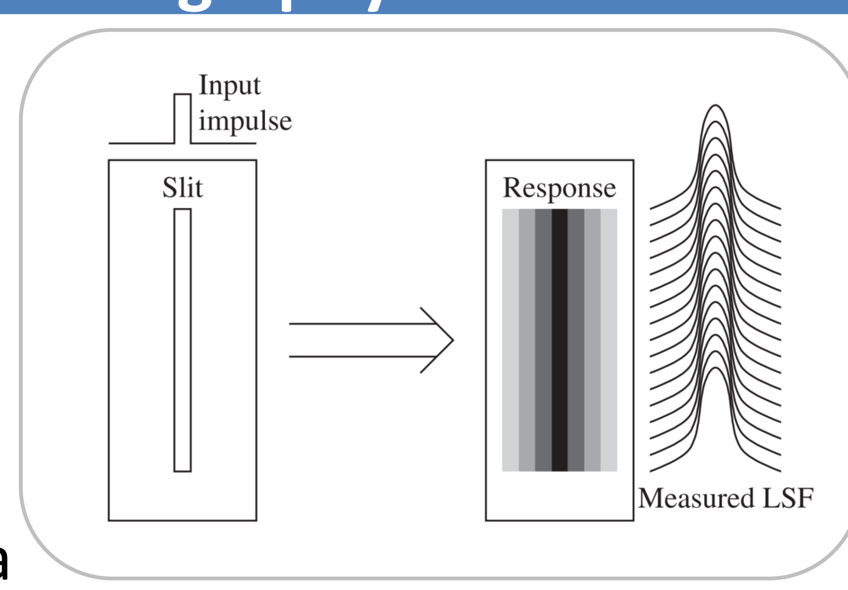
We demonstrate a novel lithography technique which utilizes direct-write laser lithography to extend the DOF to ~100 µm, enabling fine pitch patterning on high topography substrate.

Warpage[1]:
- **CTE mismatch of molding compound and dies.**

Test Vehicle		TV-1	TV-2	2.5X mTV
InFO Size (mm²)		850	1250	2100
RDL layers		3x RDLs	3x RDLs	5x RDLs
Floor Plan				
Warp@250°C (um) (-) C4	Modeling	1x	1.4x	3.5x
	Exp.	1x	1.1x	3x
Warp@25°C (um) (+) C4	Modeling	1x	1.5x	3.6x
	Exp.	0.8x	1.6x	2.6x

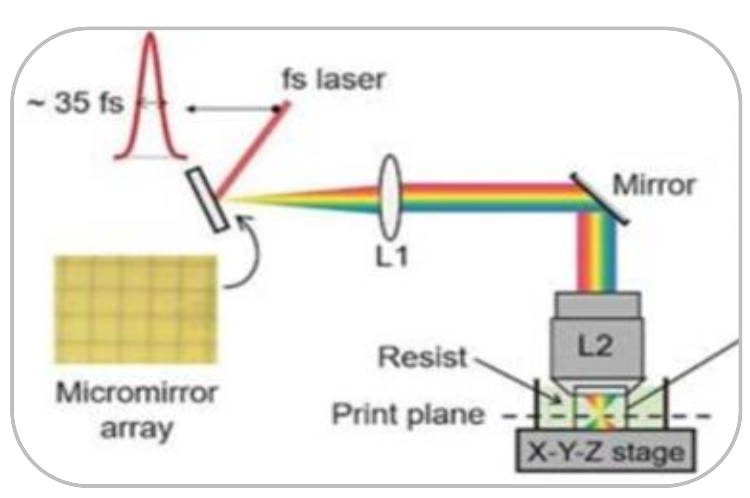
Direct-Write Laser Lithography

- For any imaging system, there is a point spread function (PSF)/line spread function (LSF).
- Resultant aerial image is the convolution of the LSF and the object.
- Intensity of laser at the surface is a gaussian:

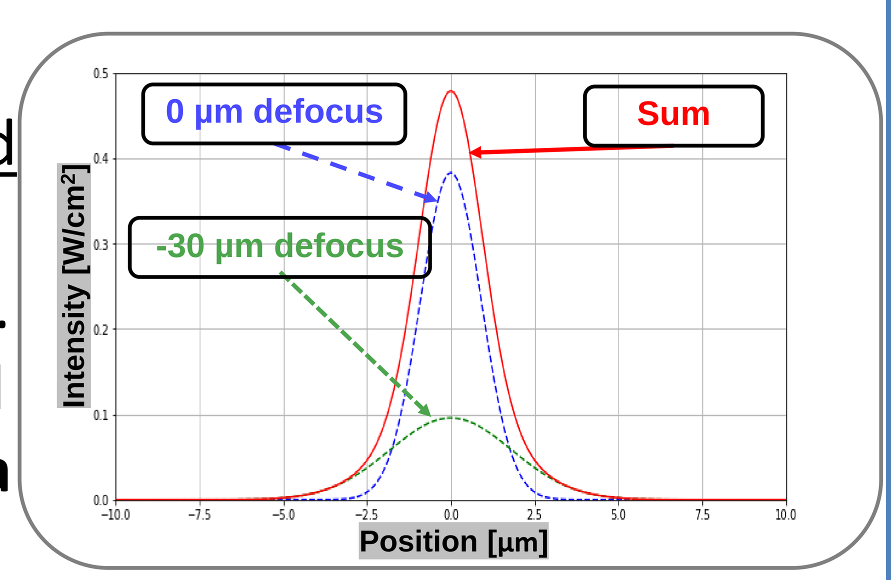


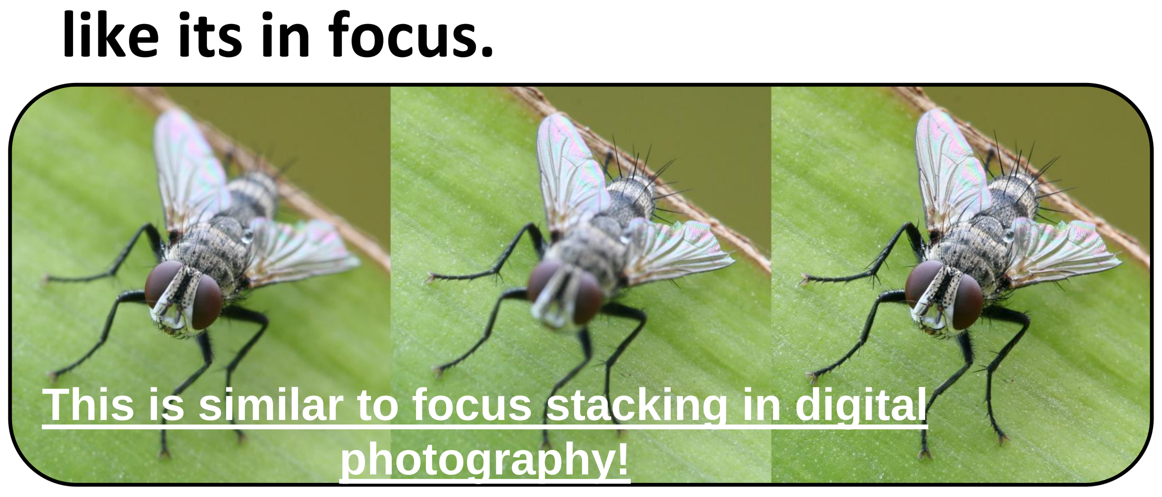
$$I(r,z)=\frac{|E(r,z)|^2}{2\eta}=I_0\left(\frac{w_0}{w(z)}\right)^2\exp\left(\frac{-2r^2}{w(z)^2}\right)$$

$$w(z)=w_0\sqrt{1+\left(\frac{z}{z_R}\right)^2}\qquad z_R=\frac{\pi w_0^2 n}{\lambda}$$



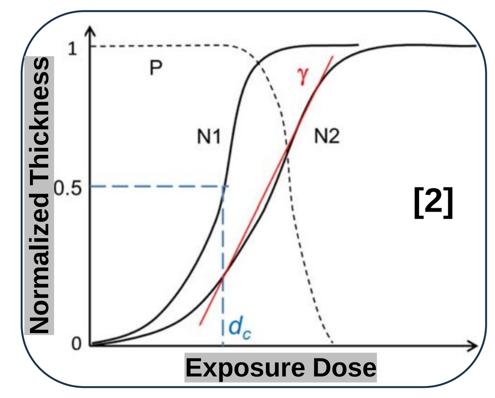
- **The variance and peak intensity of a beam is a function of defocus.**
- What if we superimpose a focused beam with a defocused beam?
- Result looks like another gaussian.
- **By adding successively defocused beams (at regular intervals over a range), the resultant curve looks like its in focus.**

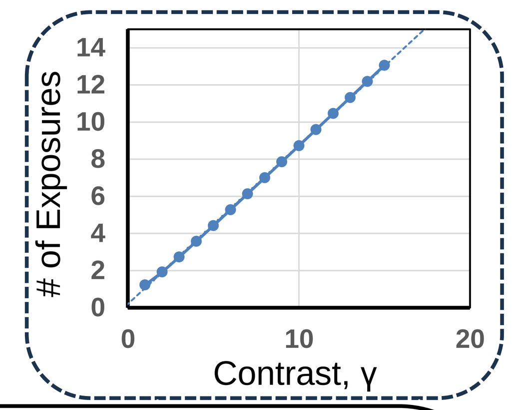


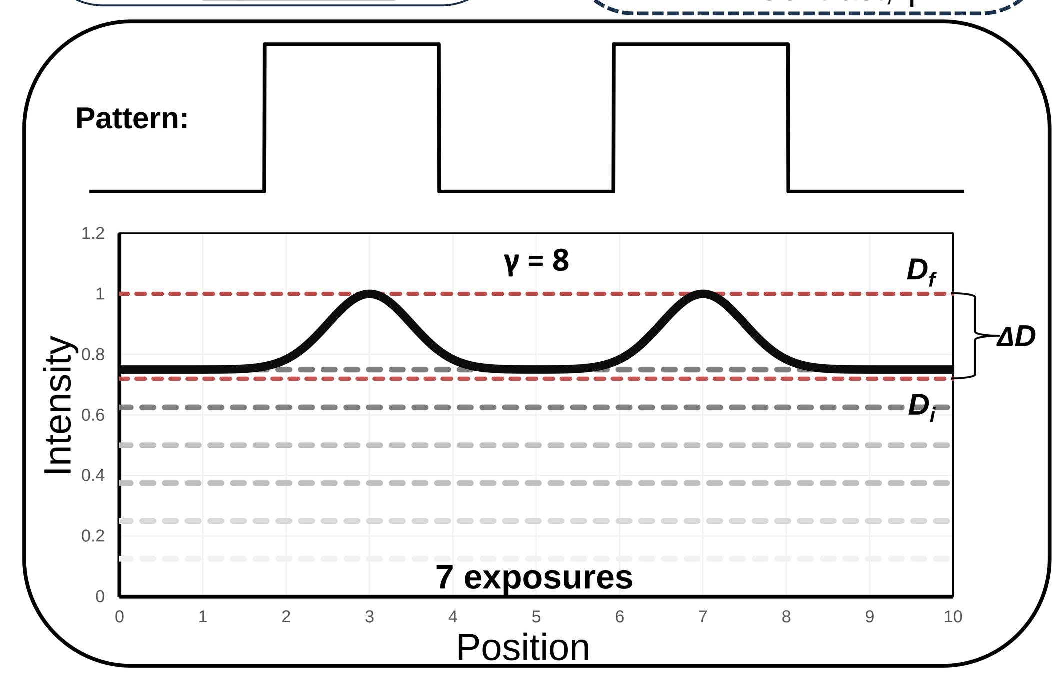


There is a limit to how many exposures we can do, depending on resist contrast.

Resist Contrast and Maximum Number of Exposures







- Resist contrast has the empirical form[2]:

$$\gamma=\frac{1}{\log_{10}\frac{D_f}{D_i}}$$

- Rearranging the above equation and equating $\Delta D = 2D_0 = 2I_0/A$ yields the following:

Maximum # of Exposures

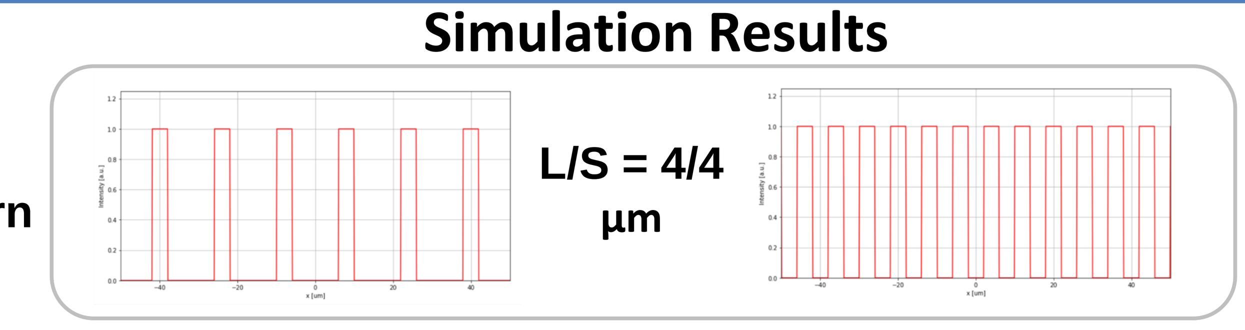
$$=\frac{D_i}{D_0}=\frac{2}{\left(10^{\frac{1}{\gamma}}-1\right)}$$

D_i = Dose at which there is an initial resist response
D_f = Dose-to-clear
D_0 = Applied dose

Results

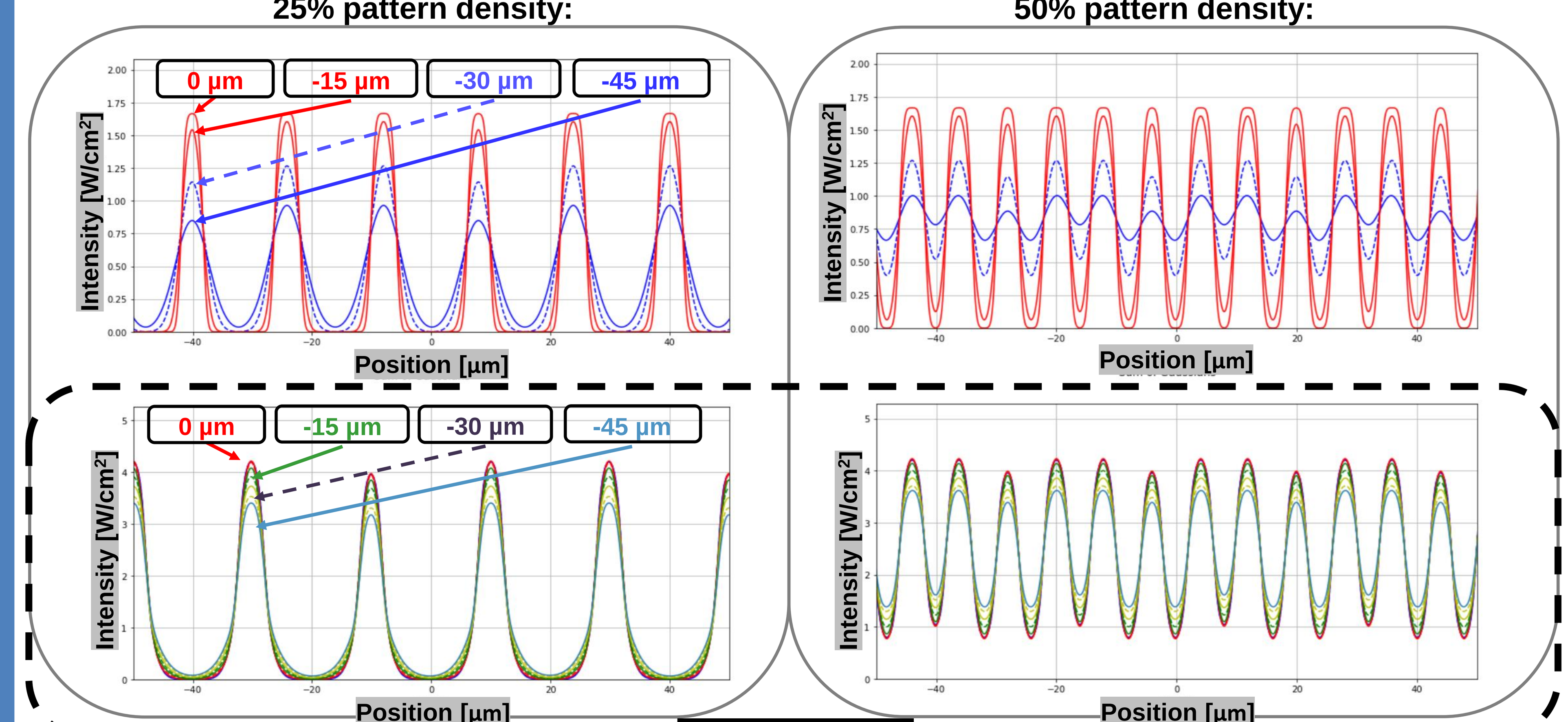
Simulation Results

Target Pattern



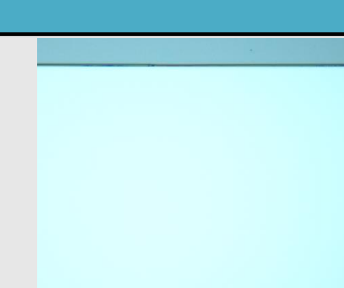
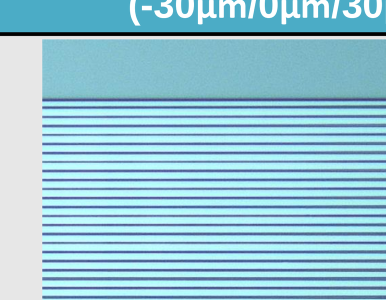
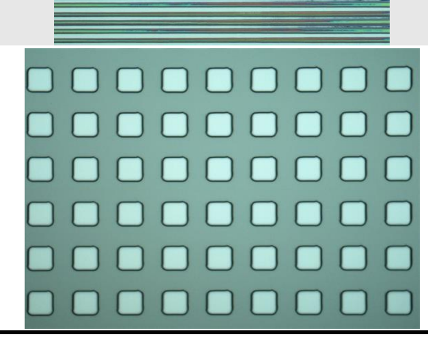
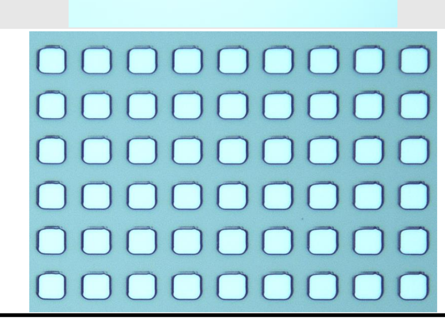
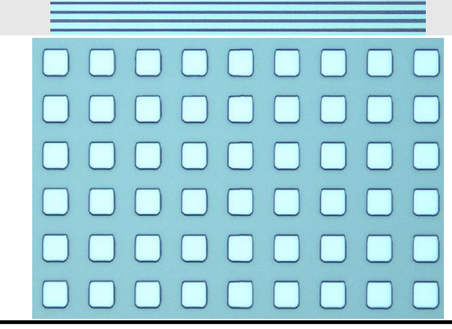
DOF = 20 µm
Pixel size = 630 nm
Focal extension done:
-30 µm, 0 µm, and 30 µm

25% pattern density: **50% pattern density:**



Experimental Results

Coat: AZ 5214E 3000 rpm (1.75 µm)/Develop: AZ MiF 300 (50s) — Patterns defocused -50 µm

Feature	POR	20% Overdosed	Focal Extension (-30µm/0µm/30µm)
2 µm L/S			
16 µm Square			

By using this technique, we can pattern 2 µm features over 100 µm of topography and address warpage.

Conclusion

- We demonstrate a novel lithography technique to enable fine-pitch patterning on high topography substrates.
- This will enable us to pattern 10 µm die-to-die (D2D) I/O wiring on the FlexTrate™ using TrueAdapt™[3].

We thank MivaTek Global LLC and the UCLA CHIPS Consortium for their continued support.

References

[1] Y. P. Chiang. IEEE 71st Electronic Components and Technology Conference (ECTC), 2021 **[2]** B. Radha. Nanoscience, 2013. **[3]** G. Sabbir. IEEE 73rd Electronic Components and Technology Conference (ECTC), 2023.

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