Exploiting phase-shifting low-n, low-k absorbers for dense contact hole patterning in EUV lithography

SPIE.

*Chaowei Huang, Pokai Chang, and Peichen Yu**

National Yang Ming Chiao Tung University, No. 1001, University Road, Hsinchu, Taiwan

NYCU NATIONAL YANG MING CHIAO TUNG UNIVERSITY

ABSTRACT

Low-n, low-k absorbing materials offer superior contrast for EUV attenuated phase-shifting masks compared to conventional absorbers like TaBN. However, aggressive scaling of dense contact holes intensifies mask 3D effects, limiting achievable density. This work establishes design conditions for molybdenum-based quasi-phase-only masks for square and triangular contact arrays. For 0.33-NA EUV systems, minimum pitches are 28.9 nm (k_1 = 0.35) for square lattices and 27.3 nm (k_1 = 0.33) for triangular lattices, with triangular lattices demonstrating superior scaling potential for future DRAM and logic contact layers.

INTRODUCTION

As DRAM scaling intensifies, patterning high-density contact hole arrays with sufficient contrast and process windows has become critical in EUV lithography. While attenuated **phase-shift masks (attPSMs)** using low-n, low-k materials improve imaging metrics such as NILS and contrast, they still face **severe Mask 3D (M3D) effects** and inadequate sidelobe suppression at aggressive k_1 factors.

This work proposes Quasi-Phase-Only Masks (Quasi-POMs) using Molybdenum (Mo) for dense 2D contact hole patterning. Unlike previous 1D-focused studies, we investigate frequency-doubling mechanisms for 2D arrays, comparing square versus triangular lattice configurations. Mo's exceptionally low n and k values enable strong phase modulation with minimal absorption loss.

Through analytical derivation and rigorous simulations, we demonstrate that triangular lattice **Quasi-POMs achieve 27.3 nm pitch (k_1 = 0.33) under 0.33-NA systems, outperforming square lattices (28.9 nm, k_1 = 0.35)**. This nearly **13.4% density improvement** provides a robust pathway for next-generation high-density memory fabrication.

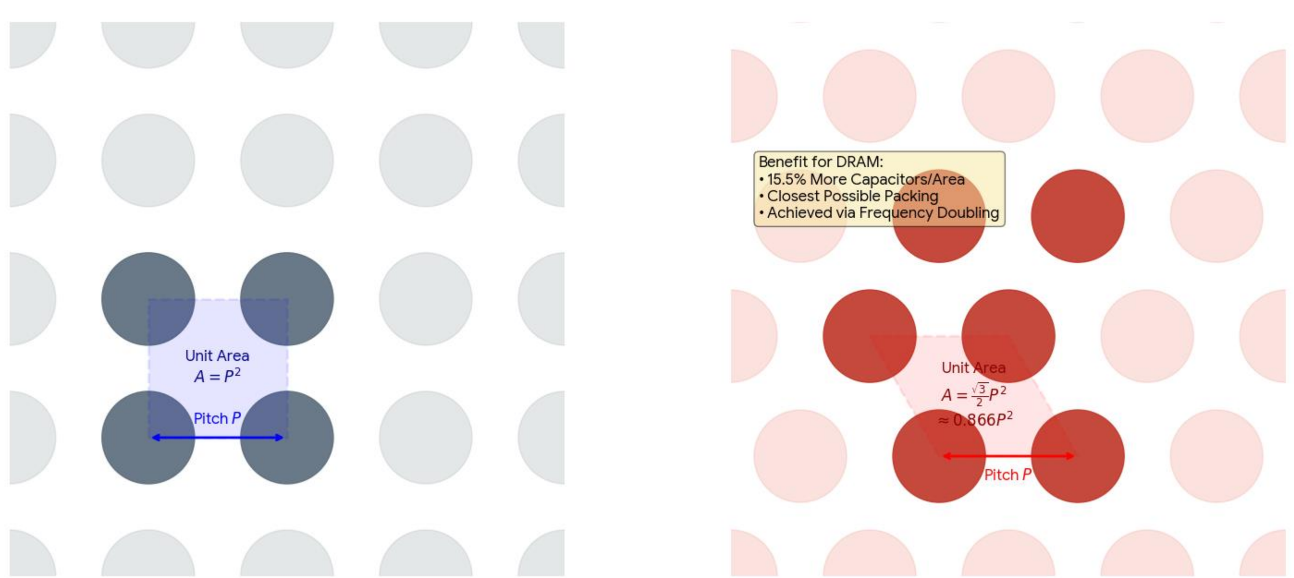
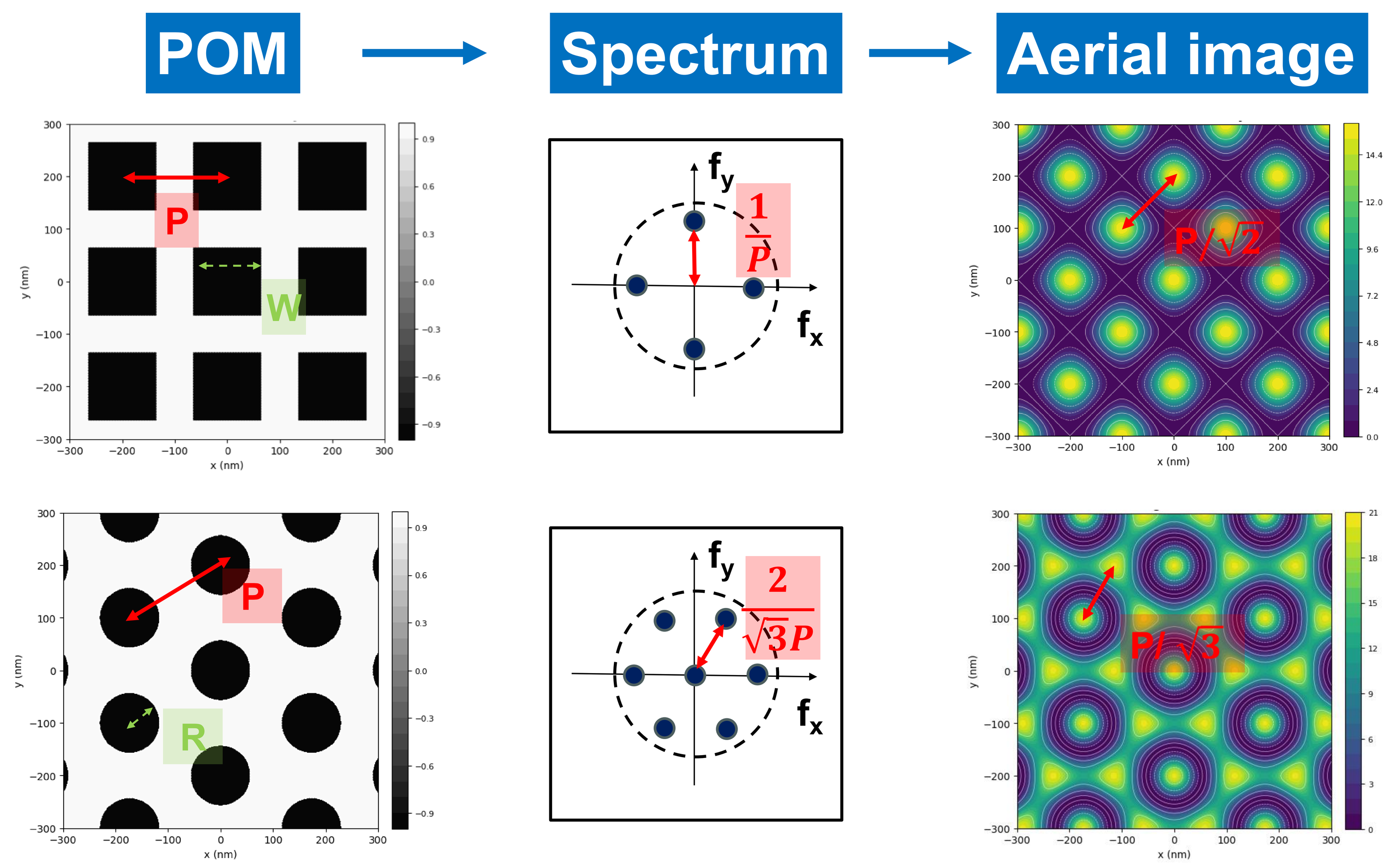


Figure 1. Triangular lattices allow for denser packing. Left: Conventional square lattice arrangement; Right: triangular lattice arrangement.

METHODOLOGY

For coherence light source($\sigma = 0$), and pure POM, we can get Aerial image by doing fouier transform.



For Contact hole array and Triangular Lattice POM can achieve not frequency doubling, but $\sqrt{2}X$ and $\sqrt{3}X$ Increase.

For **Contact hole array (square lattice) minimum pitch** on resist is :

$$P_{min} = \frac{P}{\sqrt{2}} = \frac{1}{\sqrt{2}}\frac{\lambda}{NA} = 28.9nm\ (k_1 = 0.35)$$

For **Triangular lattice minimum pitch** on resist is :

$$P_{min} = \frac{P}{\sqrt{3}} = \frac{1}{\sqrt{3}}\frac{2\lambda}{\sqrt{3}NA} = 27.3nm\ (k_1 = 0.33)$$

Unlike square lattices where zeroth-order suppression is required, triangular lattices require the zeroth-order amplitude to be -1.5 times the six first-order amplitudes to balance the main pattern and sidelobes.

By considering the condition, we have:

$$1 - \frac{4\pi R^2}{\sqrt{3}P^2} = 1.5\left(\frac{2R}{P}J_1\left(\frac{4\pi}{\sqrt{3}}\frac{R}{P}\right)\right)$$

Best duty ratio for triangular lattices is :

$$\frac{R}{P} = 0.27$$

SIMULATION RESULTS

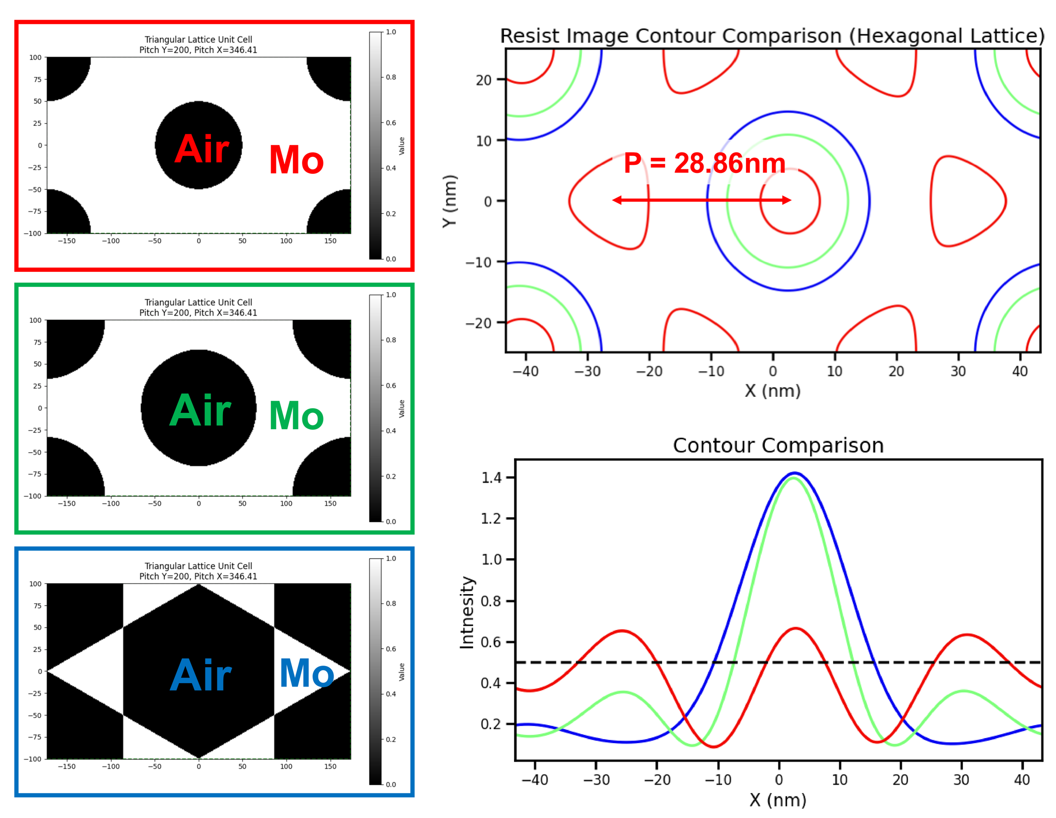
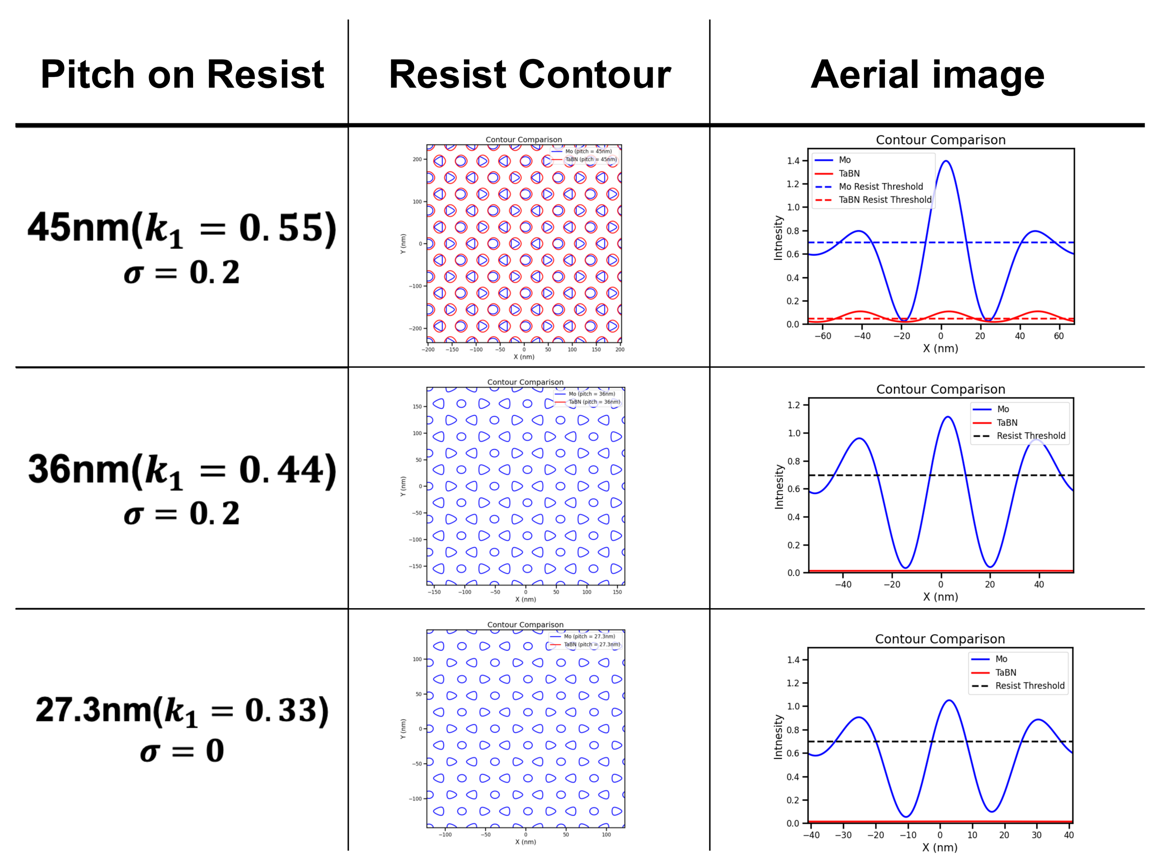
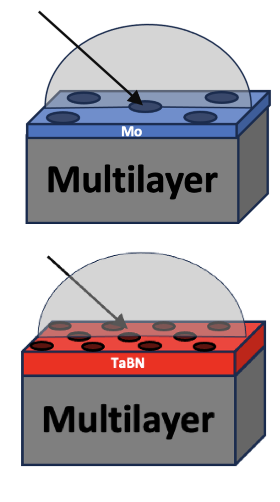


Figure 2. Mask pattern variations and aerial image analysis for triangular lattice.





	Mo	TaBN
Thickness	48nm	80nm
n	0.921	0.953
k	0.00644	0.031

Figure 3. Aerial image and resist contour comparison between Mo Quasi-POM (blue) and TaBN conventional absorber (red) at different pitches.

CONCLUSIONS

This work establishes a Mo-based Quasi-POM design framework achieving 27.3 nm pitch (k_1 = 0.33) for triangular lattice contact holes under 0.33-NA EUV, outperforming square lattices (28.9 nm) and delivering 13.4% density improvement. The key design principle requires negative zeroth-order amplitude ($C_0 = 1.5C_1$) for triangular lattices versus zeroth-order suppression for square lattices, with optimal duty ratio R/P = 0.25–0.27. Mo-based designs maintain sufficient contrast where conventional TaBN absorbers fail. Triangular sidelobes cause contact distortion at extreme pitches, suggesting future SMO optimization.

Triangular Mo Quasi-POMs enable the minimum achievable pitch of 27.3 nm (k_1 = 0.33) for 2D contact arrays in 0.33-NA EUV lithography—the fundamental resolution limit for dense pattern transfer.

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Further author information:(Send correspondence to Peichen Yu)

Peichen Yu : Email : peichen.yu@nycu.edu.tw