Simulation of Glancing Angle Deposition

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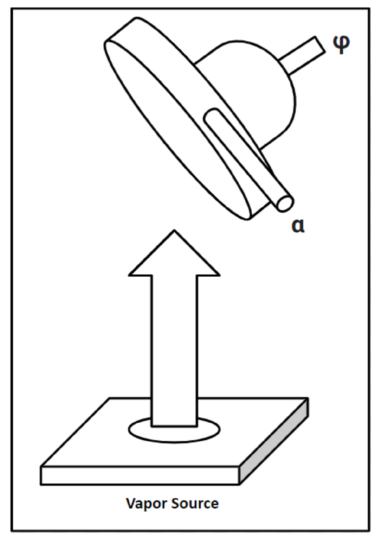
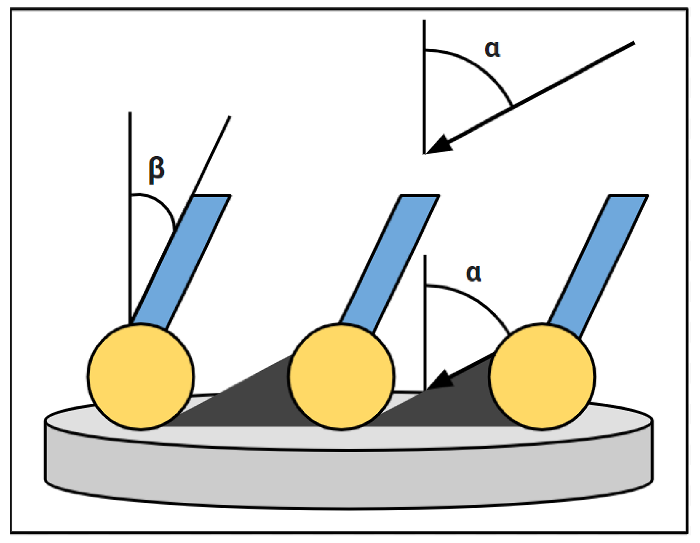
Introduction

Glancing angle deposition (GLAD) is a type of physical vapor deposition process used to manufacture nanostructured thin films. GLAD has applications in sensing, optics, and magnetic storage technologies. Various nanofeatures can be produced using GLAD such as chevrons, ribbons, helices etc. Nanostructures are produced through ballistic shadowing – where natural particle islands cast "shadows" and prevent the further growth of columns in that shadowed region.

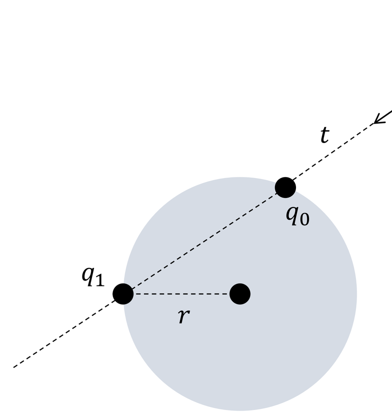




This study puts forth a way to simulate the GLAD process in a 3D environment. By applying different inputs such as incidence angle, rotation rate, deposition rate, the outcome of the simulation can be manipulated.

Applying this simulation will allow for a more accurate prediction of seeding strategies, percent coverage, growth angles, and an overall outcome of the GLAD process.

Collision Resolution



$$q_0 = p + t\vec{d}$$

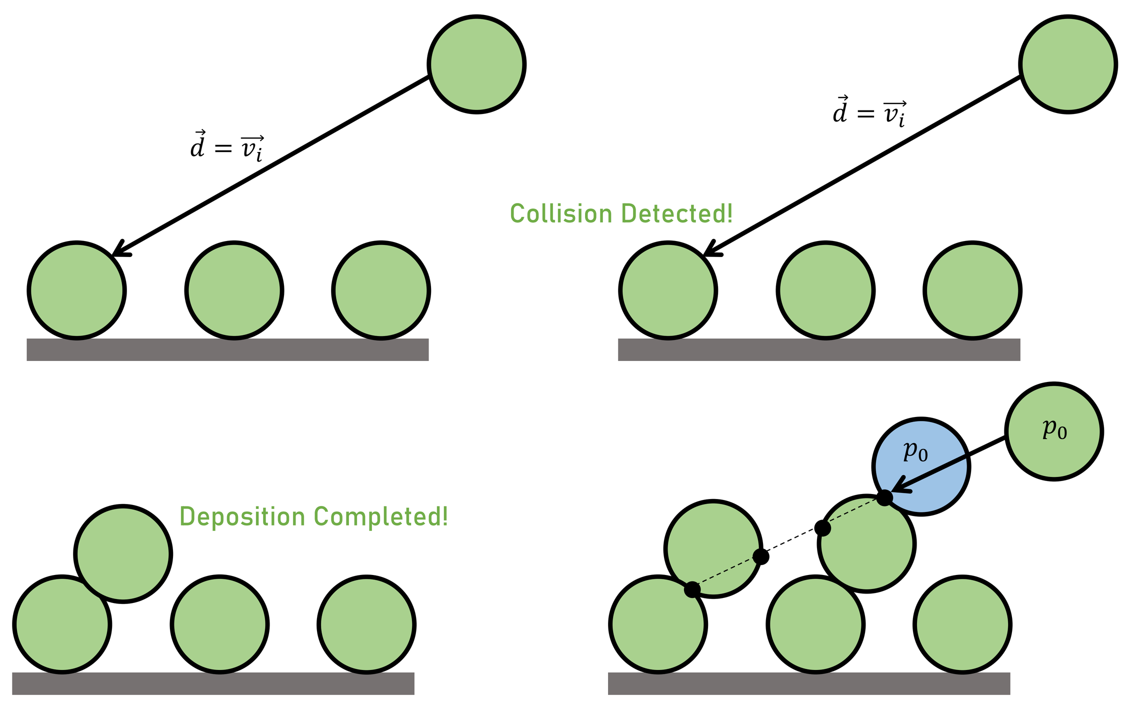
$$f(q_0) = (x-c)\cdot(x-c) - r^2 = 0$$

$$f(p+t\vec{d}) = (p+t\vec{d}-c)\cdot(p+t\vec{d}-c) - r^2 = 0$$

$$f(p+t\vec{d}) = \underbrace{(\vec{d}\cdot\vec{d})}_{a}t^2 + \underbrace{2\vec{d}\cdot(p-c)}_{b}t + \underbrace{(p-c)\cdot(p-c) - r^2}_{c} = 0$$

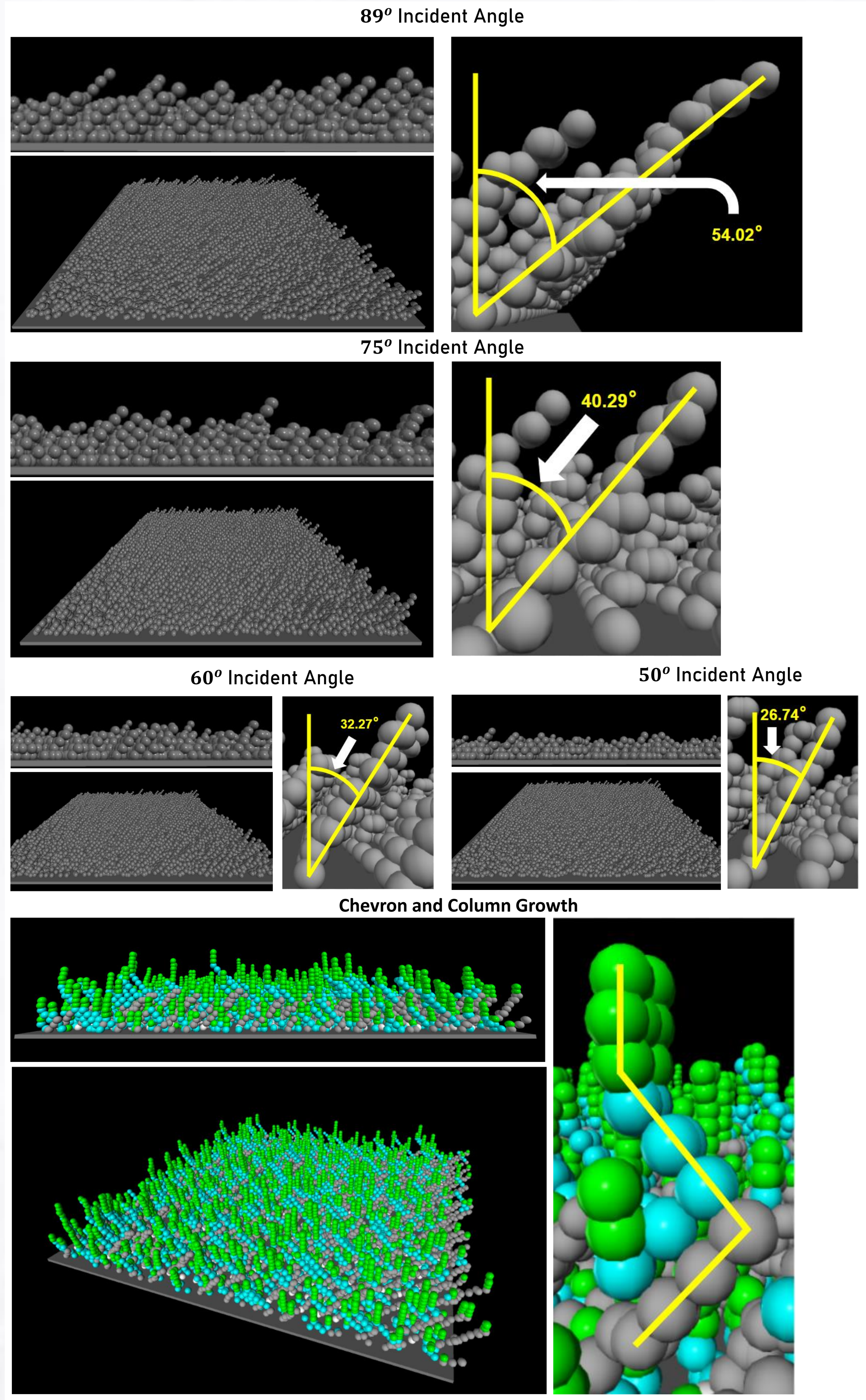
$$t_{1,2} = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$$

Only smaller part used to find q_0.



The smallest value for t is used since it allows for shadows to form between particle islands. It also causes extinction of columns in this shadowed region.

Simulation Results

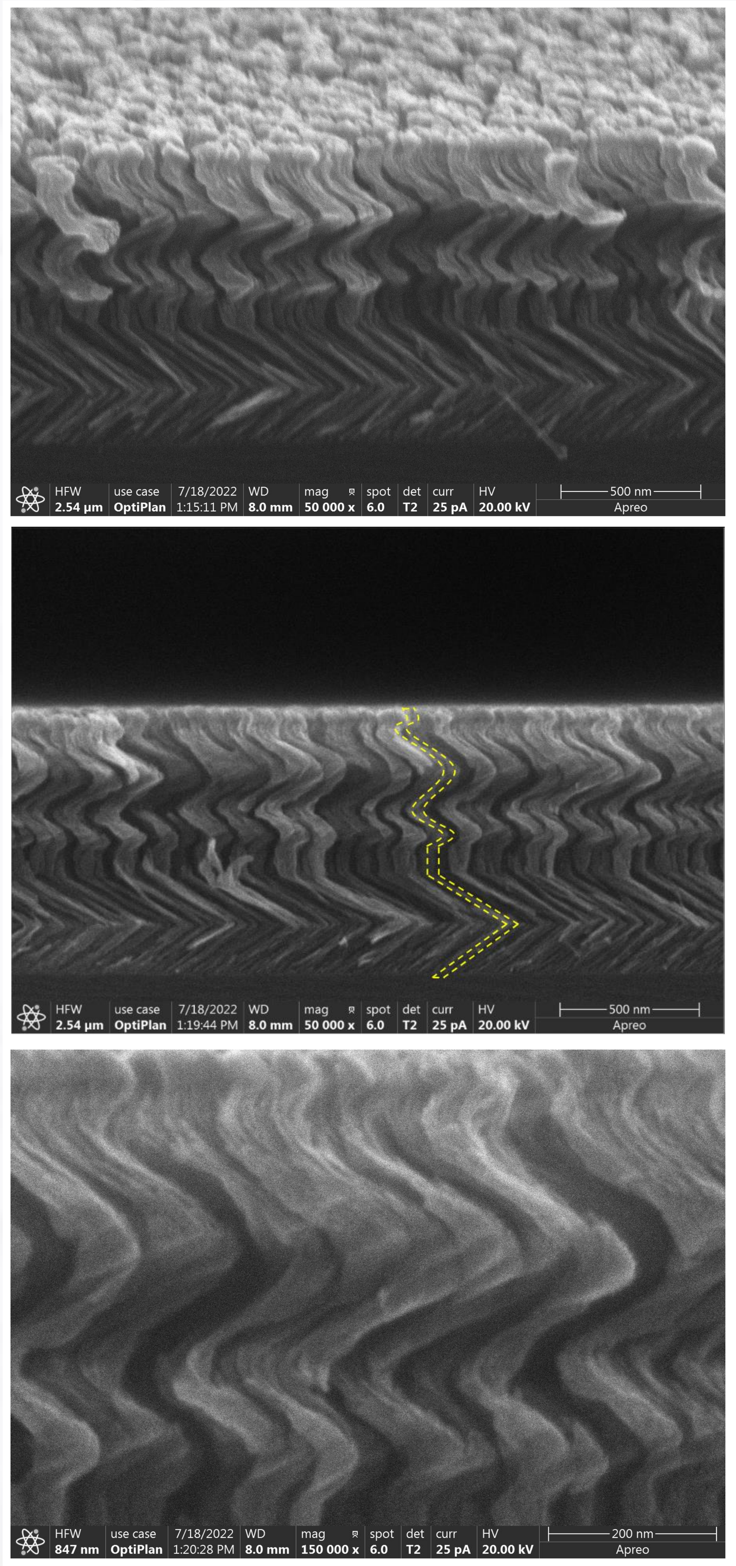


Program Efficiency

Time Complexity	Iterations	Render Time (s)
$O(n^4)$	$x < 2{,}500{,}000{,}000$	38.55
$O(n^3+n^2)$	$x < 510{,}000{,}000$	12.36
$O(n^3+n)$	$x < 500{,}000{,}000$	9.79
$O(sn^3)$	$x < 100{,}000{,}000$	3.54

The table shows the time complexity of 4 different collision resolution algorithms with 10,000 input size for a 10-layer column at 89^o. The 4[th] algorithm was used for the rest of the tests.

Experimental Results



GLAD recipe:

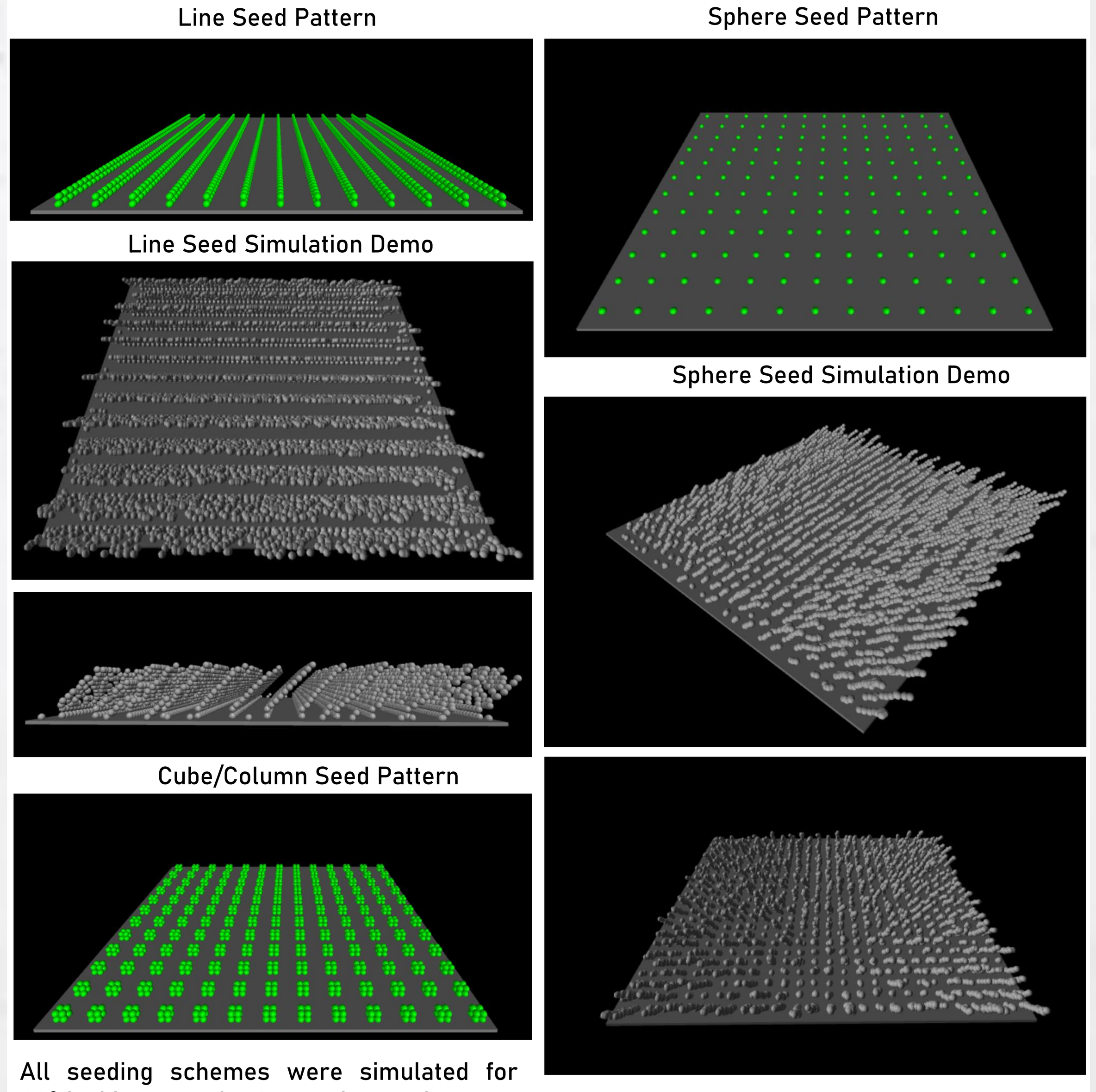
- Chevron:
  $\alpha = 75^\circ, \varphi = 0;$
  $\alpha = 80^\circ, \varphi = 180^\circ$
- Column:
  $\alpha = 80^\circ, \omega = 5\,rpm$
- Helix:
  $\alpha = 80^\circ, \omega = 0.04\,rpm$

GLAD characteristics:

- Chevron + Column Height: 430 nm
  - Nominal Col. Height: 166 nm
  - Column Height: 98 nm
- Helix Height: 500 nm
- Feature Width: 38 nm

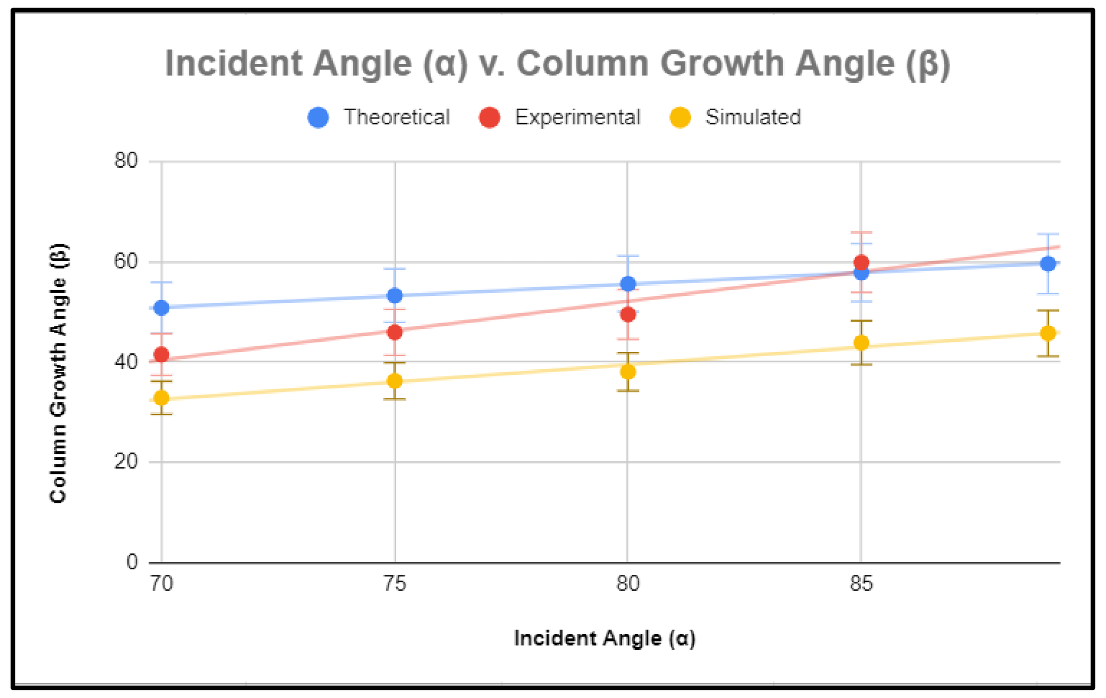
GLAD:
E-Beam evaporator system was used as the PVD process to deposit Germanium onto a silicon substrate.

Seeding Patterns



All seeding schemes were simulated for 89^o incidence angle. β was observed $< \alpha$

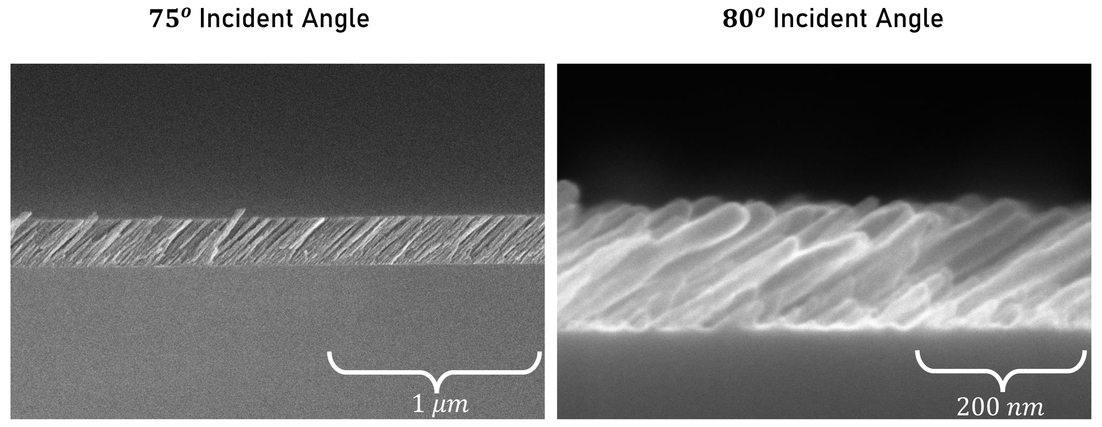
Incidence Angle (α) vs. Column Angle (β)



Tait's Rule: Theoretical β

$$\beta = \alpha - \sin^{-1}\left(\frac{1-\cos\alpha}{2}\right)$$

Figure shows varying incidence angles along with their observed column growth angles.



Conclusions

This study demonstrates the use of a Monte-Carlo fashion simulation of glancing angle deposition. We incorporated the VPython package to implement this simulation. We demonstrated the deposition of natural seeds, onto which nanostructures were grown. Our simulation results – growth angle and percent coverage – were demonstrated with respect to inputs such as incidence angle and initial seeding. We further qualitatively compared experimental and simulated results and received favorable results. The simulation results could help predict fabrication results of GLAD for applications in optics, sensing, electronics.

Our collision resolution algorithm has a time complexity of $O(sn^3)$ where s is the total number of simple features (columns) required to make a complex shape. No GPU hardware acceleration was used to render the simulation.

Simulation Videos

Acknowledgements

National Nanotechnology Coordinated Infrastructure
KY MULTISCALE
The NSF NNCI Multi-Scale Manufacturing & Nano Integration Node
NSF Award ID #1950137
NSF Grant No. #2025075
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