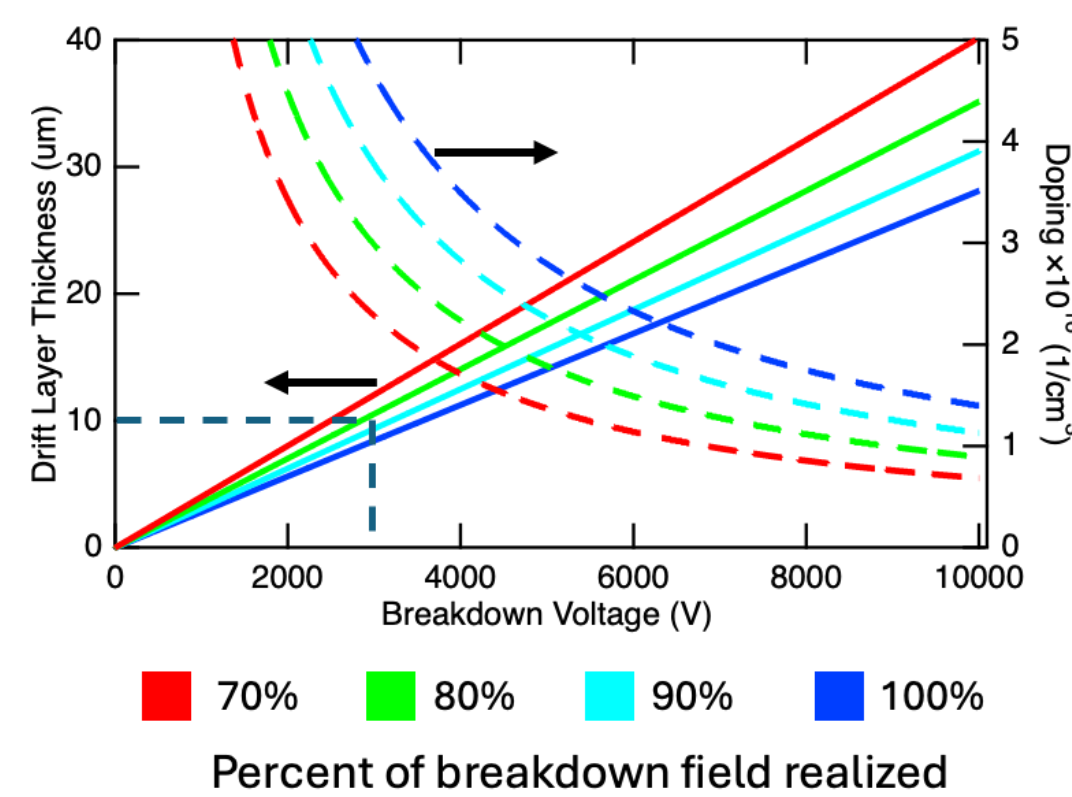


Homoepitaxial Growth of β -Ga₂O₃ on Miscut (100) Substrates using MOCVD

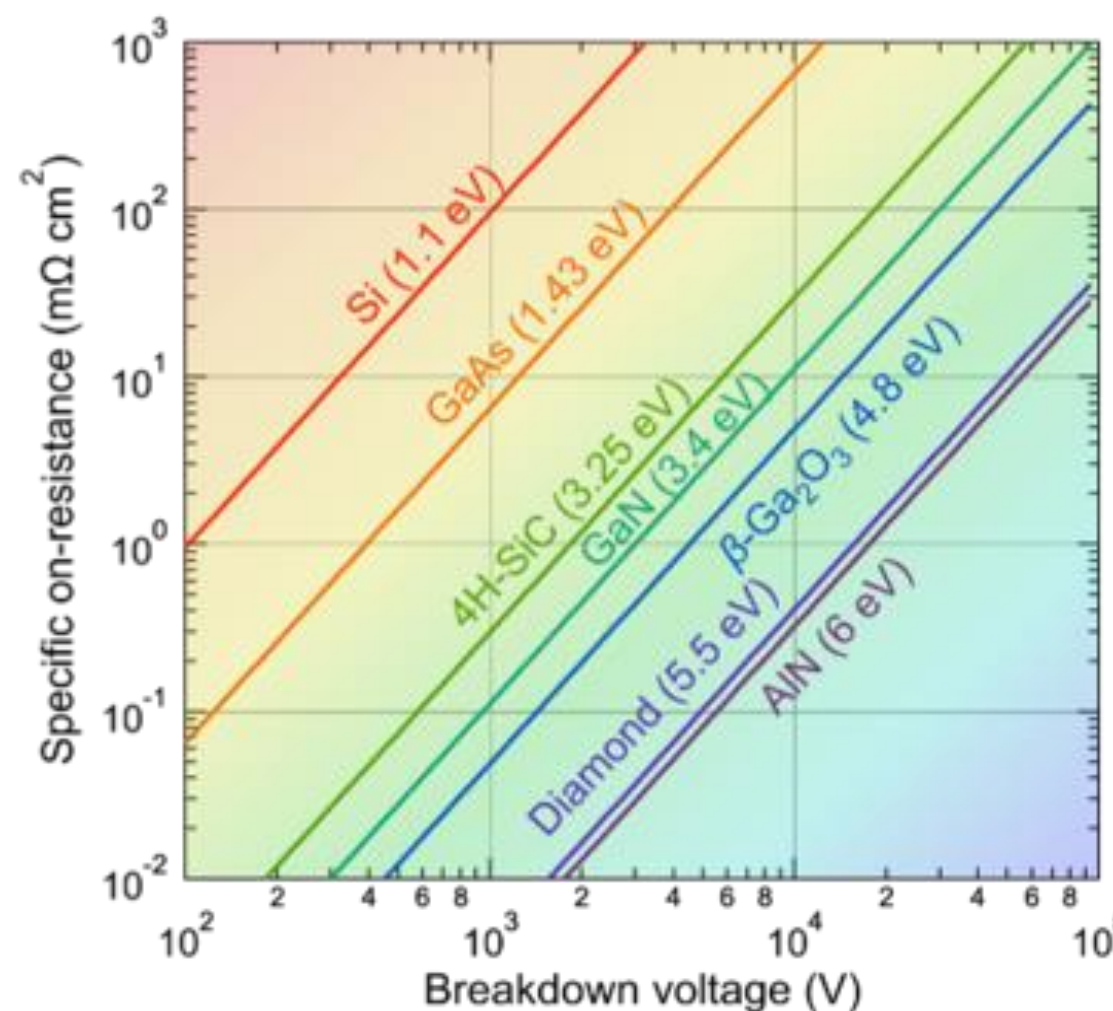
Soren Hellyer, Josh Buontempo, Cameron Gorsak, Hari Nair

Background

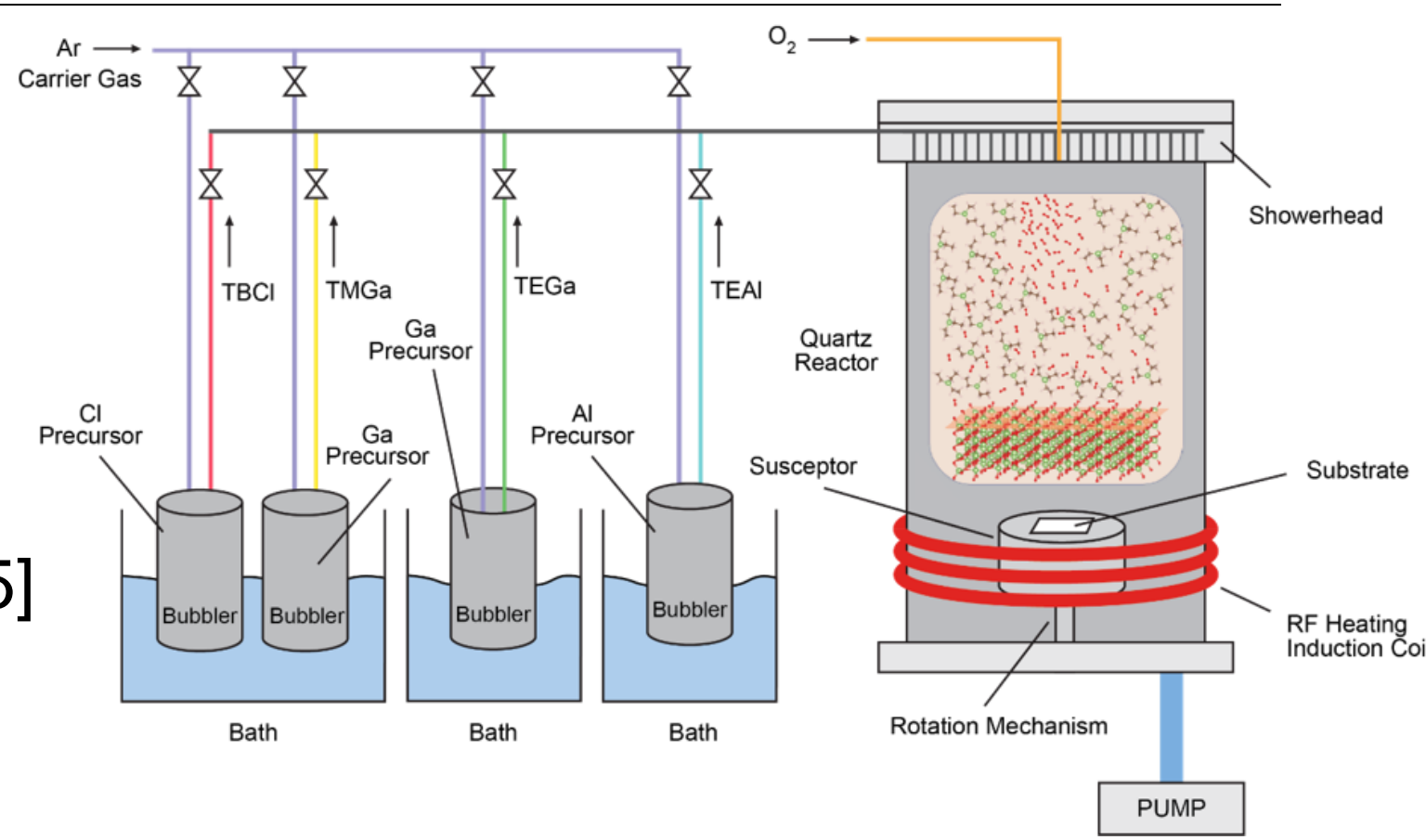
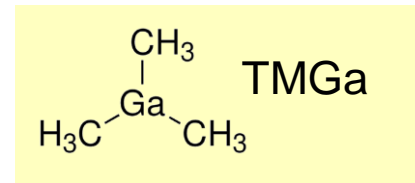
- β -Ga₂O₃ is an ultra-wide band gap material (4.8 eV) [1, 2]
- Potential for use in high voltage applications
- Candidate for vertical devices; Requires:
 - Thick drift layers (>10 μ m)
 - Smooth films (< 1 nm RMS roughness)
 - High growth rates (> 3 μ m/hr)
 - Control of low background doping



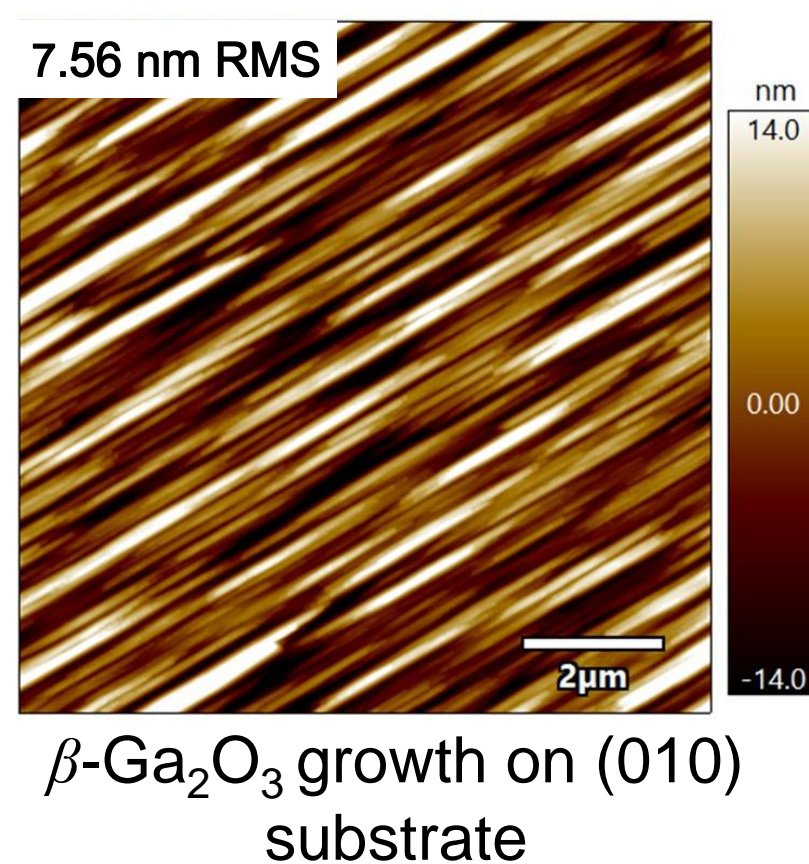
Courtesy of Dr. Jonathan McCandless



- High growth rates can be achieved with Metal-Organic Chemical Vapor Deposition (MOCVD) [3, 4]
- Faster growth rates achieved with Trimethylgallium (TMGa) [5]

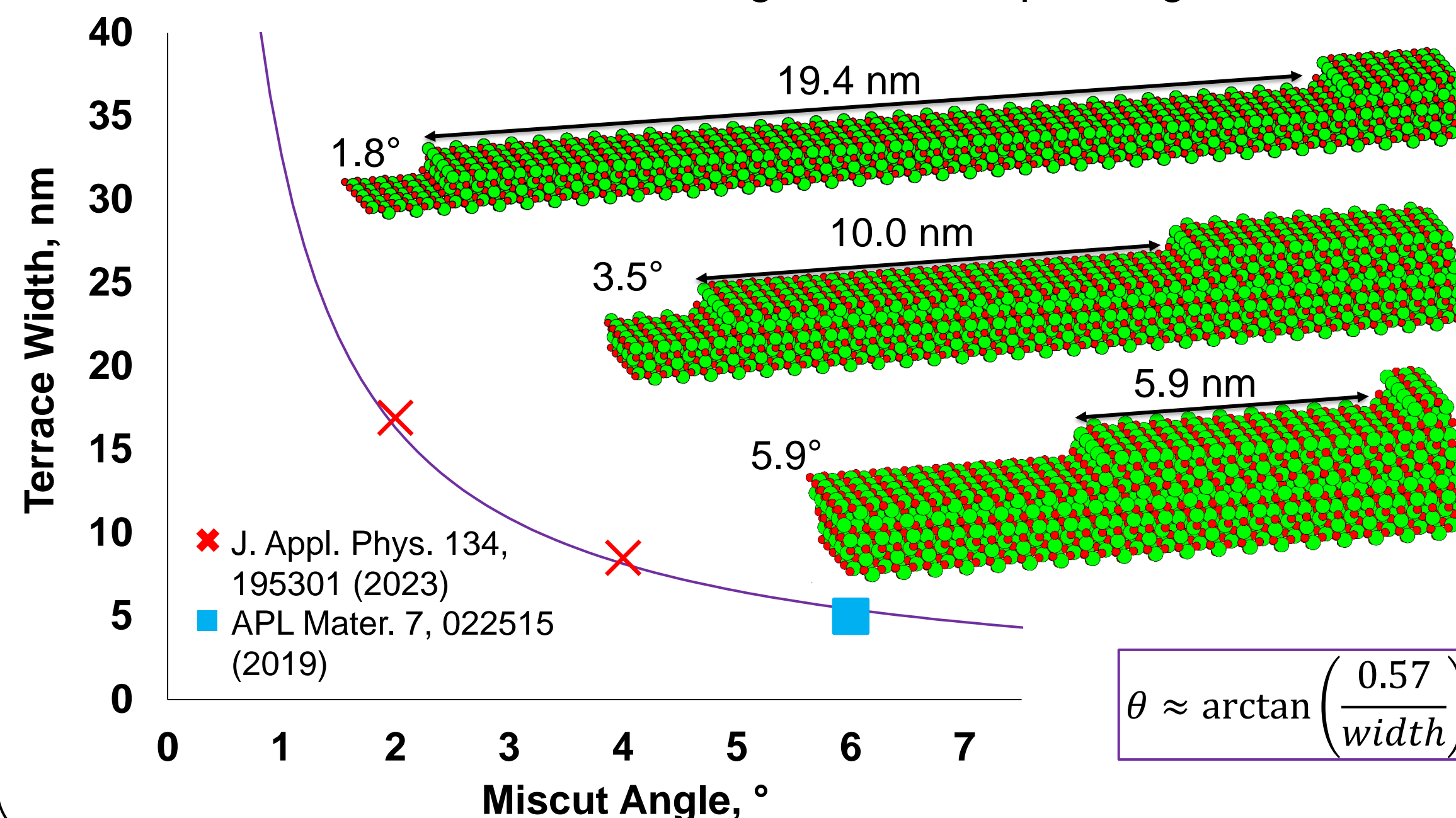


- Previous β -Ga₂O₃ growths have been on (010) substrates
 - Extended defects from substrate [6, 7]
 - Thick (010) films have high RMS roughness
 - Surface facets towards lower energy surfaces: (100) & $\bar{2}01$ [8]
- Growth on on-axis (100) substrates lead to twinning
 - Twinning occurs during island growth
 - Can be prevented with step-flow growth



Miscut Angle

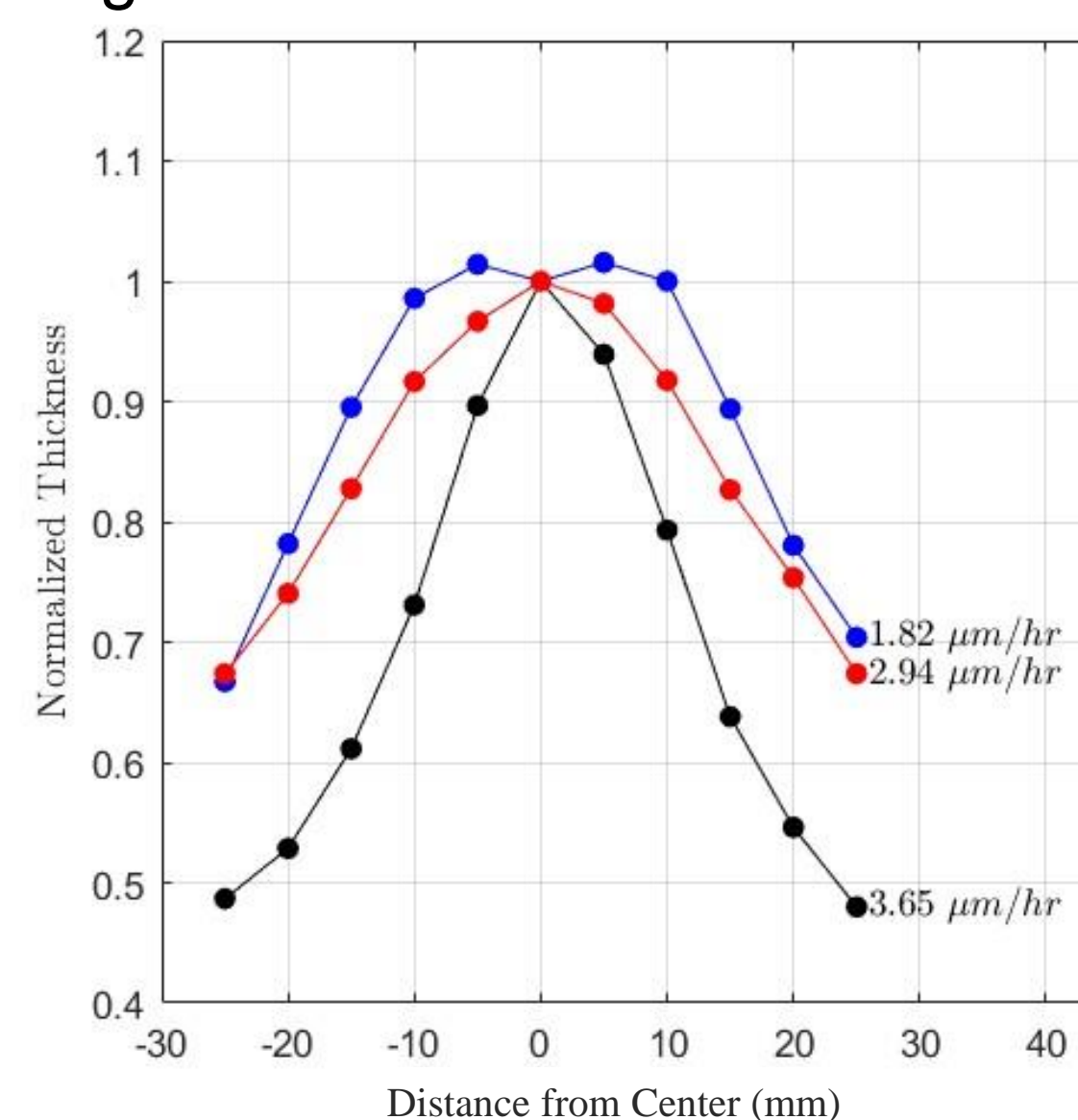
- (100) steps are introduced with a miscut angle
- Increased terrace width with decreasing miscut angle [9]
- Terrace width influences island growth or step-flow growth



Growth Uniformity

- Growth uniformity is important for scalability
- Tests performed with Ga₂O₃ grown on c-plane Al₂O₃
- For a given total flow, increasing outer/inner flow ratio:
 - Increased growth rate
 - Decreased uniformity
- Higher total flow
 - Increased growth rate
 - Decreased uniformity

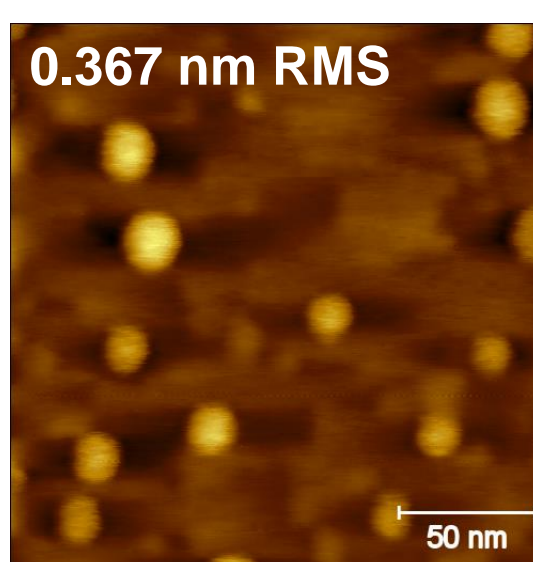
Lower Total Flow
Higher Outer/Inner
Higher Total Flow
Lower Outer/Inner (best)
Higher Total Flow
Higher Outer/Inner



Results

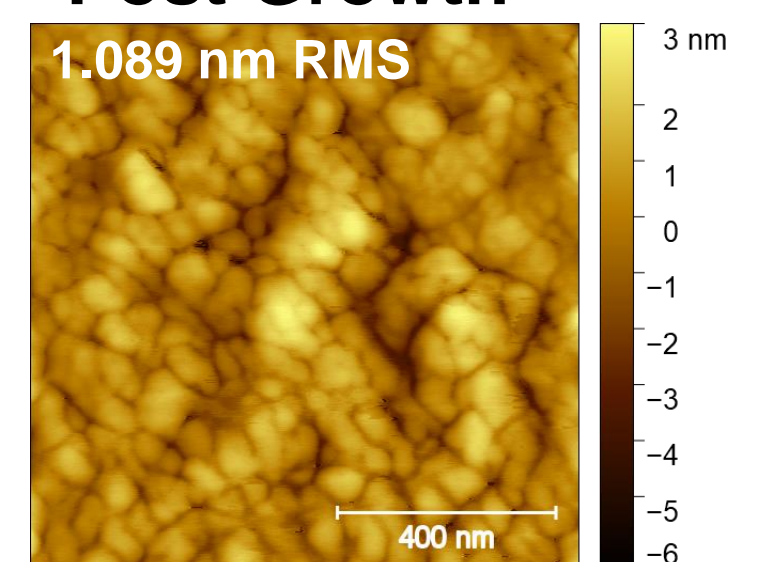
- 5 μ m thick films were grown at 3 μ m/hr
- 4° & 6° miscut both had sub-micron RMS roughness
- 2° shows Island Growth
- 4° & 6° show either step-flow growth or step-bunching

Post Anneal

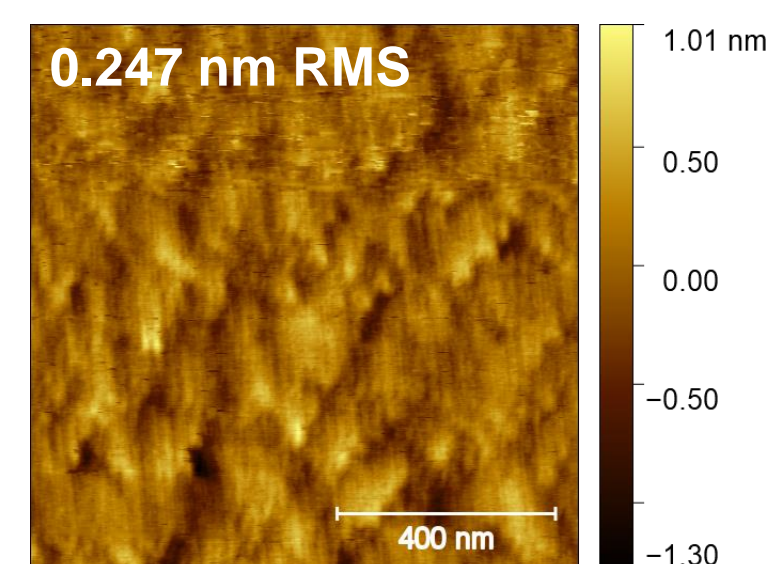
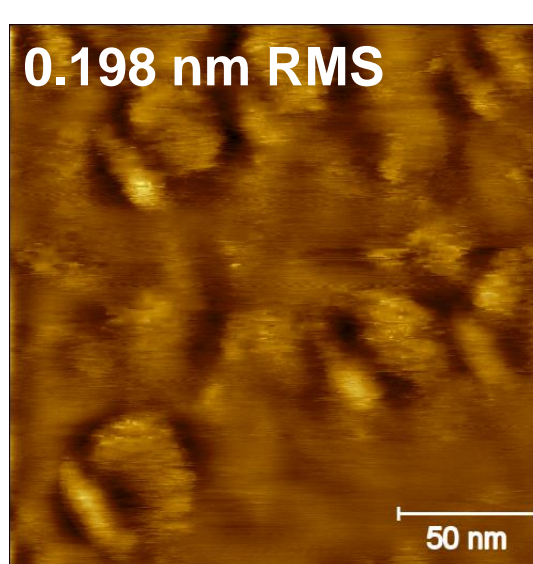


2° Miscut

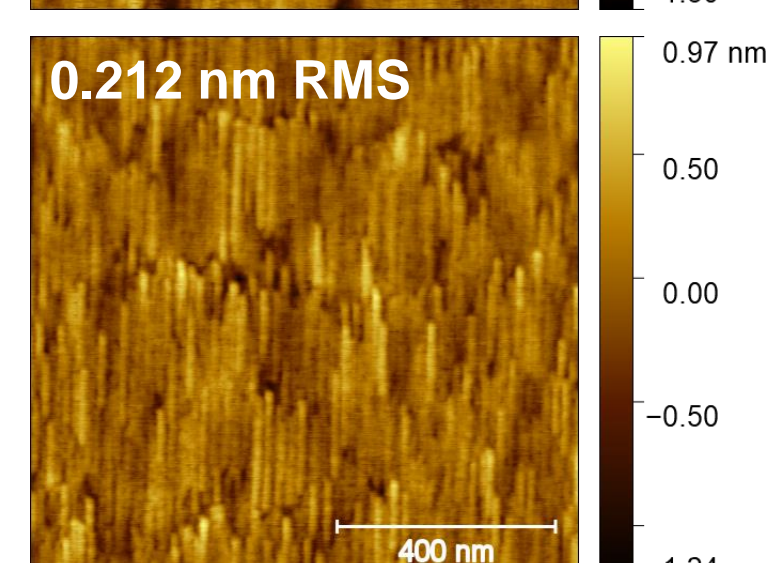
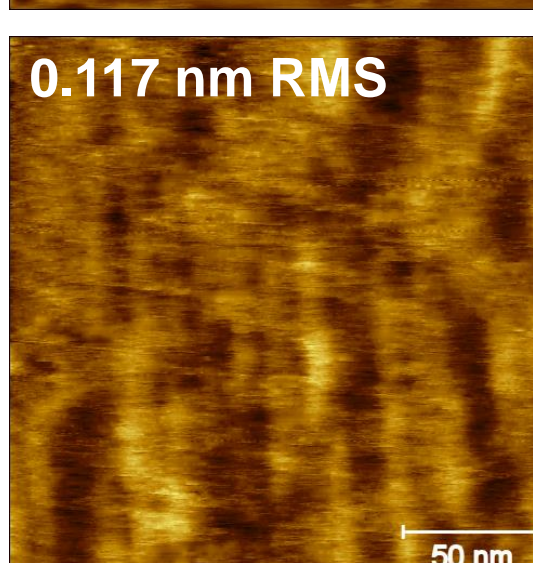
Post Growth



4° Miscut



6° Miscut



Summary & Future Work

- 5 μ m thick β -Ga₂O₃ films were successfully grown on (100) miscut substrates
- 4° & 6° miscuts show promise for vertical devices
- Improve anneal conditions to improve growth
- Perform *in-situ* anneal with MOCVD
- Perform electrical characterization using Hall measurements

[1] Guenter Wagner et al, Phys. Status Solidi A 211, No. 1 (2014)
[2] Christoph Janowitz et al, New J.Phys. 13 085014 (2011)
[3] Yuewei Zhang et al, APL Mater. 7, 022506 (2019)

[4] Jeffrey Tsao et al, Adv. Electron. Mater. 4, 1600501 (2018)
[5] George Seryogin et al, Appl. Phys. Lett. 117, 262101 (2020)
[6] Jacqueline Cooke et al, J. Vac. Sci. Technol. A 41, 013406 (2023)

[7] Katsuhiko Nakai et al, Jpn.J.Appl.Phys. 54 051103 (2015)
[8] Sai Mu et al, APL Mater. 8, 091105 (2020)
[9] Robert Schewski et al, APL Mater. 7, 022515 (2019)