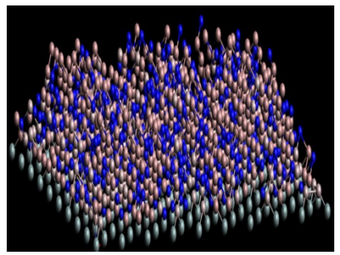
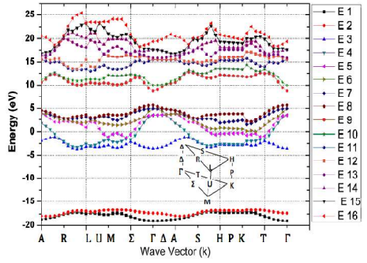
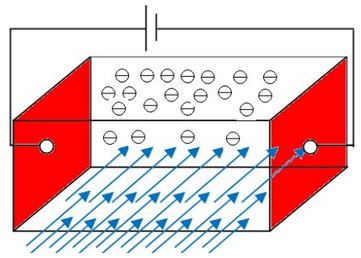
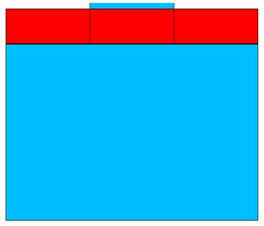
Low- & High-pressure MOCVD Reactors
Epitaxial Growth Solution
Solar Cell

Technology of Next Level
driven through innovation









CHALLENGES: SOLAR CELL TECHNOLOGY

- **III–V Multijunction Solar Cell Integration with Silicon**
- *Achieving high-efficiency solar cells* and *at the same time driving down the cell cost*
- Materials Used : Group III-V Arsenides, Phosphides, and Nitrides, Group IV, IV-VI and II-VI semiconductors
- III–V compound solar cells: shown performance improvement at ~1% (absolute) increase per year, with a recent record efficiency of 44.7%
- III–V solar cells on Si substrate through heteroepitaxial integration
- Among competing photovoltaic technologies, the expensive cost is biggest impediment in their large-scale deployment for terrestrial applications

Performance: Solar Cell Technology

- Most significant cost III–V solar cells is the cost of substrate.
- Typically, GaAs or Ge substrates used for III–V multijunction solar cell growth,
- Smaller in diameter and significantly more expensive than Si substrate
- Transitioning from a 4” Ge substrate to a 8” Si substrate would reduce 60% cost

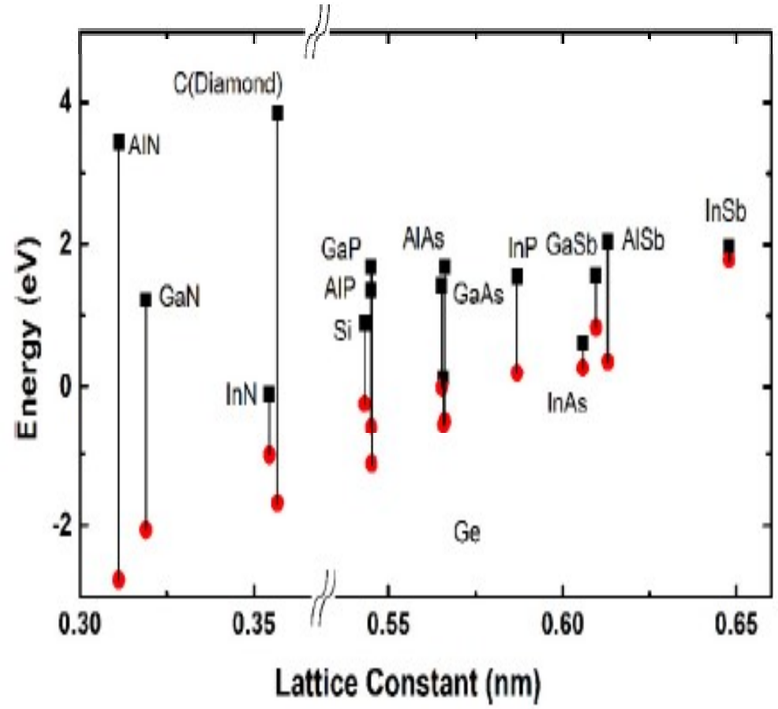
Technology	Efficiency	Room for Improvement
1J Single junction Si	~25%	Saturated
2J InGaP/GaAs based multijunction	32.9% -36.5%	Performance improvement at ~1% increase
3J InGaP/GaAs//Si or III-V Nitrides	~40%	
4J AlGaAs/ GaAs/Si/InGaAs tandem	=44.7%	Reported further room for improvement
Thin strained layers (SLs) and superlattices	~ 35%	To reduce Defects

Design Criteria & Challenges

Two key approaches for integrating III–V multijunction solar cells on Si substrate:

(i) Heteroepitaxial growth: ***very promising path with several challenges e.g. lattice mismatch, strain, types of defect generation***

(ii) Mechanical stacking or wafer bonding: *suffers with wafer bowing or cracking due to large thermal mismatch, free from lattice-mismatch, depends upon Hetroepitaxy growth*

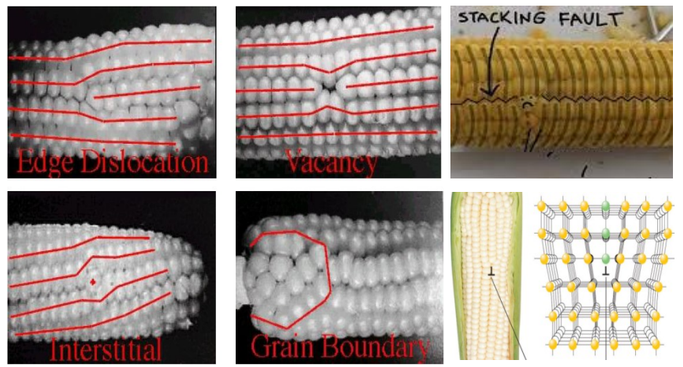


*E.T. Yu, J.O. McCaldin, T.C. McGill, Band offsets in semiconductor heterojunctions, in: E. Henry, T. David (Eds.), Solid State Physics, Academic Press, 1992, pp. 1–146

Heteroepitaxy: Challenges

- ❑ Band gaps Tuning : depends on material thickness, composition, defects etc
- ❑ Efficient absorption from the incident light: thickness of active region
- ❑ High thermal/chemical stability: allow operations in extreme conditions in space
- ❑ 4% lattice-mismatch between GaAs & Si: Epitaxy of GaAs on Si extremely challenging
- ❑ Formation of defects and dislocations
- ❑ Such defects limit solar cell performance

Substrate	Si	Al_2O_3	SiC	Bulk GaN	AlN
Lattice Mismatch (%)	17	16	3.4	-	2.5
Thermal Conductivity	150	35	490	260	319
Resistivity (ohm-cm)	10^4	10^{14}	~10^{12}	-	>10^{14}



Challenges: GaN/Si Epitaxy

❑ *GaN directly on Si or Sapphire* encounters several challenges: large lattice mismatch (*16% to 20.4%*), thermal expansion coefficient (*TEC*) mismatch ~ *53%*

❑ *GaN buffer layer : Avoid formation of cracks* and several *other technological challenges*

❑ *Stacks of $In_xGa_{1-x}N$ layers* on GaN buffer layer : *To balance compressive and tensile strain*

❑ Growth of the GaN buffer layer on the Si substrate : *Still not well understood*

❑ Formation of *amorphous SiNx*, deteriorates crystalline quality.

❑ Pre-nitridation process of Si substrate greatly influences surface morphology. However, nitridation time and temperature highly influence strain generation

❑ NH_3 pre-flow with smaller step size time and the optimum substrate temperature are still ***debatable*** to achieve a single-crystalline GaN on Si or Sapphire substrates

Challenges: GaN/Si Epitaxy

- ❑ GaN-on-Si devices recently attracted much attention *reliable Solar cell* applications due to *cost & large size Si substrates* with possibility *of co-processing in CMOS foundries*
- ❑ Contributor to incident power loss at multiple interfaces due to *parasitic effects*
- ❑ Type of conductivity & formation mechanism of parasitic channel is ***controversial***
- ❑ Formation of a p-type conductive channel at the GaN/Si interface,
- ❑ Formation of an n-type electron channel induced by the strong polarization field at the GaN/Si interface.
- ❑ Understanding the behaviors of the parasitic interfaces at multiple junctions: *crucial to reduce the losses*
- ❑ Unsolved problem requires an unambiguous identification of these issues and require lot of investment to do ***Hits & Trials***

TNL - Epitaxy Process Solution

Innovative Atomistic Scale Reactor Simulation without use of Continuum models

TNL Framework

- MBE Reactor Process
- CVD Reactor Process
- PECVD Reactor Process
- MOCVD Reactor Process (Vertical Precursors Flow)
- MOCVD Reactor Process (Horizontal Precursors Flow)

- User's Input Growth Conditions
- Surface Profile (Roughness)
- Strain Mapping (layer by Layer
- Lattice parameter
- Defects (Vacancies, Interstitials, Dislocations, Stacking Faults)

INPUTS : MOCVD PROCESS

Chamber Condition

☐ **Showerhead Based**

☑ **Injector Based**

Injector Parameters

Chamber Volume (ltrs.)	1.4	
Chamber Pressure	10	torr
Ceiling Height (cm)	2.0	
Chamber Temperature (C)	100	
Sticking Coeff.	1	

Many More parameters details Require …….

Precurssor Condition

Number of Port: 0

Precursor 1: Select Prec...

Flow Rate: atm cc/s

Load Reaction | Step 1 | Load 1

Precurssor Condition

Number of Port: 4

Precursor 1: Select Prec...

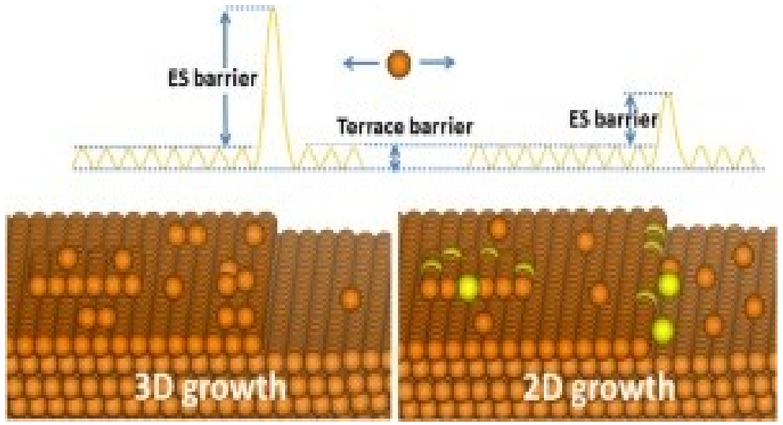
Flow Rate: m cc/s

Load Reaction | Load 1

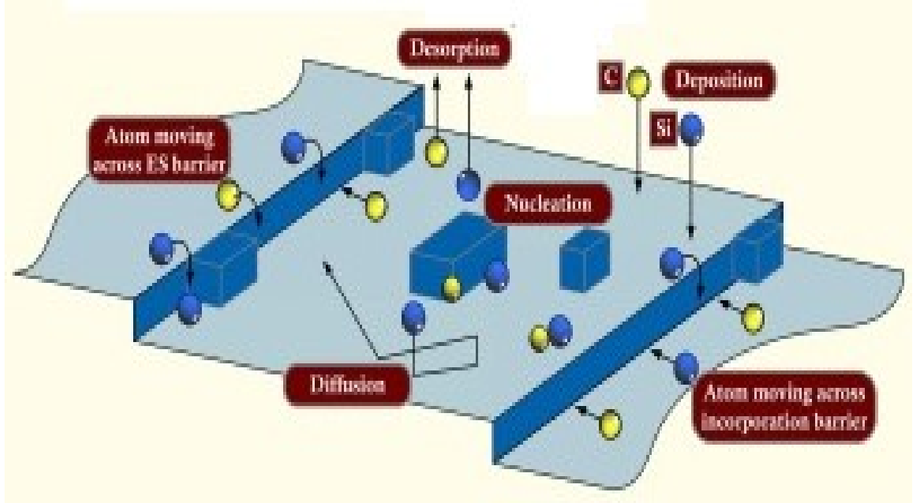
- Select Precursc
- Ga(CH3)3
- (CH3)3CAsH2
- H2
- Al(CH3)3
- NH3
- CH3
- O2

METHODOLOGY: MOCVD PROCESS

Schwoebel barrier: The atom diffuses from the site exactly above the edge atom to the site immediately next to the edge atom as;



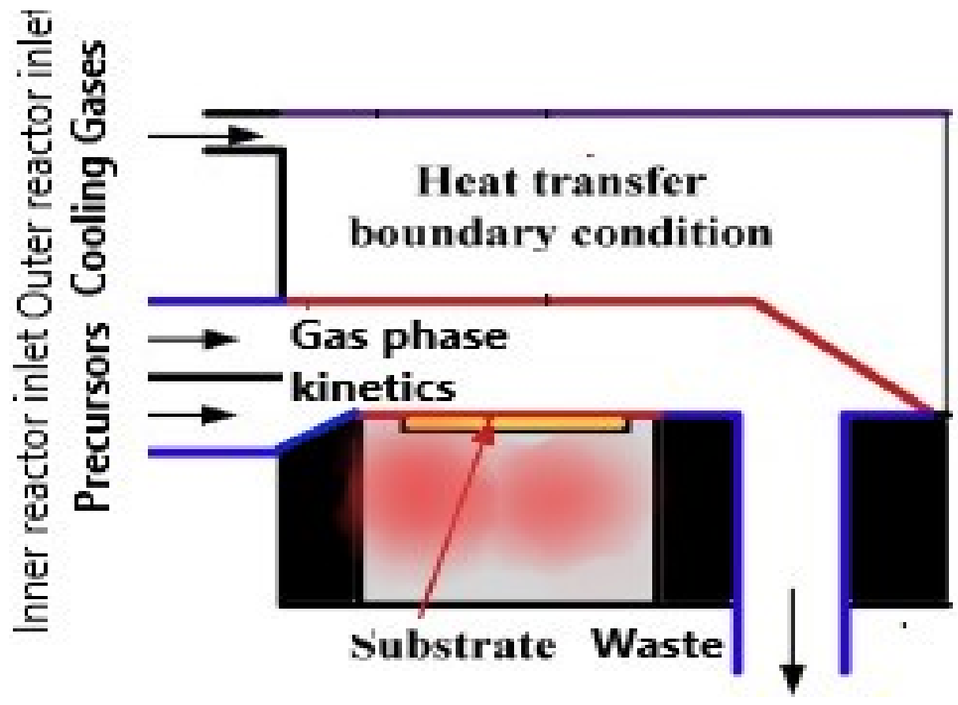
Incorporation barrier: The atom incorporates into the edge on the same surface level.



PLANETARY MOCVD PROCESS

Planetary MOCVD architecture implemented in ***TNL-Injector*** **simulator** equivalent to the **AIX 200/4 horizontal MOCVD reactor**.

Inlet of the reactor is divided into two parts by a separator through which the group III and V precursors can be fed into the upper and lower inlet respectively.



PLANETARY MOCVD PROCESS

The reactant flux, $J_A = -\frac{D_{AB}}{RT}\frac{dc_A}{dx}$ with $\frac{dc_A}{dx} \approx \frac{\Delta c_A}{\Delta x} = \frac{c_{AB} - c_{AS}}{\delta}$

where J_A is the diffusion flux of specie A, is the concentration of species A, x is the direction perpendicular to the substrate surface, *R* is the gas constant, *T* is the absolutc$_A$ e temperature. δ is the chamber boundary layer thickness.

D_{AB} is the diffusivity of the bulk stream reactants and dependent on Leonard-Jones parameters (σ, Ω) based on the Chapman-Enskog theory

$$D_{AB} = 2.7 \times 10^{-3} \frac{\sqrt{T^3\left(\frac{1}{M_A} + \frac{1}{M_B}\right)}}{p\sigma_{AB}^2 \Omega_{D,AB}}$$

M is the molecular weight, p is the pressure, σ_{AB} is the collision diameter, and Ω_D, AB is the collision integral and dependent on temperature and intermolecular potential.

Average boundary layer thickness, δ, $\bar{\delta} = \frac{10}{3}\sqrt{\frac{\mu_{mix} L}{\rho U}}$

PLANETARY MOCVD PROCESS

An Injector MOCVD reaction initiate either surface kinetic or mass transport control. Suppose C_g is the concentration of the bulk gas and C_s is the concentration of reactants at the substrate interface. The concentration of the reactants drops from the bulk to the substrate surface and the corresponding mass flux,

$$I_{gs} = h_g(C_g - C_s)$$

where h_g is the gas mass transfer coefficient, insensitive to variations in temperature.

The flux consumed at the surface $I_s = k_s(C_s)$ where $C_s = \frac{C_g}{1+\frac{k_s}{h_g}}$

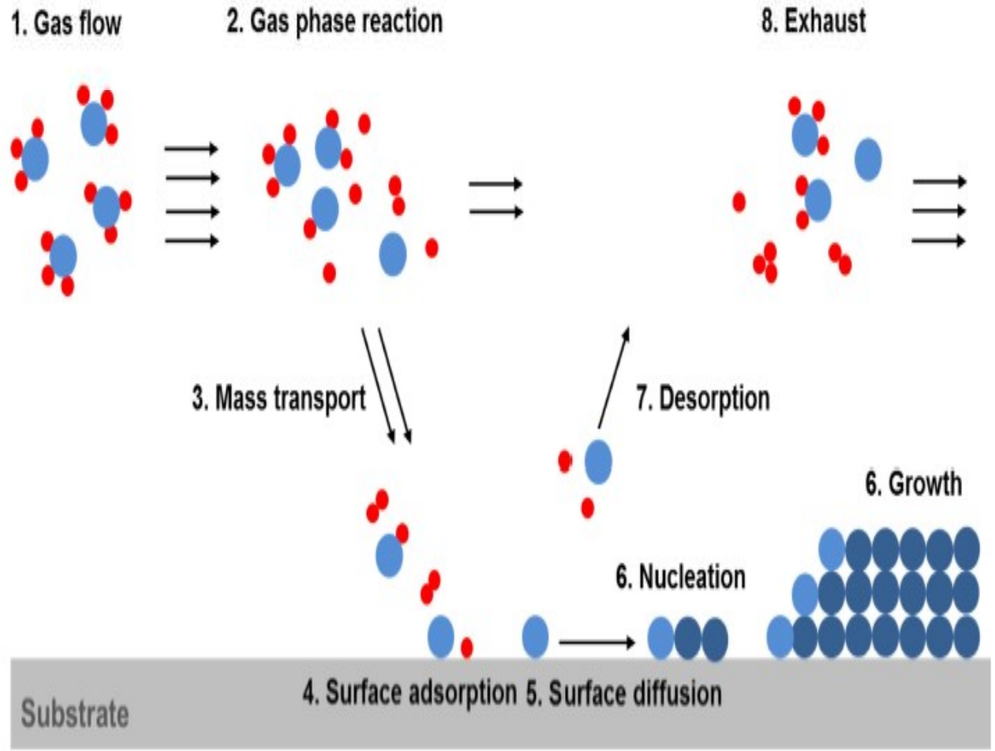
where k_s is the slowest surface reaction rate constant.

For $\boldsymbol{k_s >> h_g}$, the system dictated by mass controlled , low gas transport rate through the boundary layer limits the rapid surface reaction.

Surface reaction control dominates for $\boldsymbol{h_g >> k_s}$, the surface reaction is slow even through sufficient reactant gas is available. Additionally, h_g increases with increasing pressure and decreasing temperature and k_s follows the Arrhenius equation.

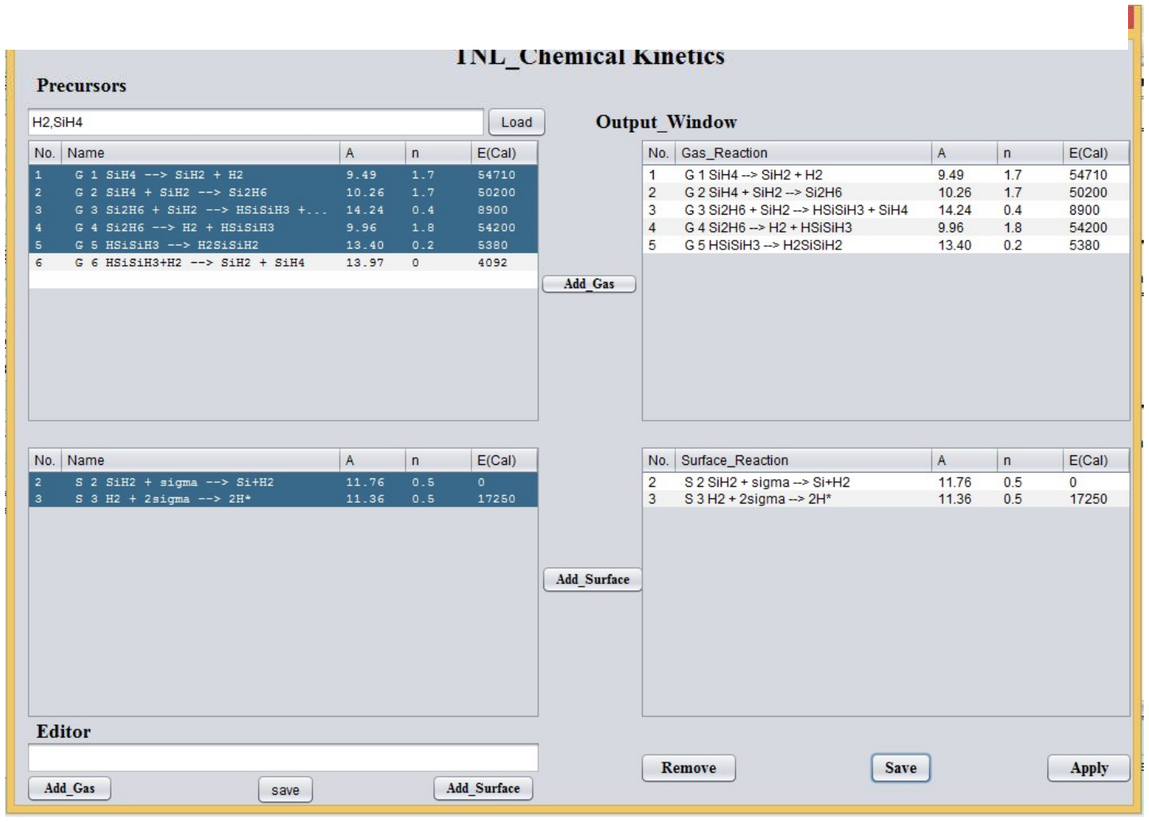
WORKING

- ❖ Gas phase kinetics
- ❖ Surface phase kinetics
- ❖ Each monolayer with atoms positions
- ❖ Defects layer by layer quantitatively and qualitatively
- ❖ Strain layer by layer
- ❖ Surface Roughness
- ❖ Lattice Constant etc.



CHEMICAL KINETICS SOLUTION

- TNL Chemical Kinetics database includes gas- and surface phase chemical reactions
- Users may chose any desired equation or set of equations for the precursors they input based on requirements
- Users have flexibilities to write their own chemical reactions



TNL Chemical Database

Precursors for MN Growth

(M = Ga, Al, In)

TMM, DMM, NH_3, AsH_3, PH_3, TBP etc.

Dopants

Cp_2Mg, SiH_4, DEZ, DETe, $CBrCl_3$ etc.

Carrier Gases: MN Growth

N_2 , H_2 , Ar etc.

Here,
TBP- tertbutylphosphine
DEZ- DiethylZinc
DETe- DiethylTelluride
$CBrCl_3$- Bromotrichloromethane

$$A + B \leftrightarrow AB$$

$$\frac{d[AB]}{dt} = \frac{k_1[A][B]^2}{1 + k_2[A] + k_3[B]^{1/2}}$$

Reaction rates in forward and reverse directions

$$k = AT^n \exp\left(-\frac{E_a}{RT}\right)$$

TMG, NH_3 & N_2/H_2/ARGON

Gas-phase Mechanisms Reactions

									$k = AT^n e^{-Ea/RT}$		
									A	n	E_a
G1	TMG	=	DMG	+	CH_3				1.00×10^{47}	−9.18	76,996
G2	DMG	=	MMG	+	CH_3				7.67×10^{43}	−9.8	34,017
G3	MMG	=	Ga	+	CH_3				1.68×10^{30}	−5.07	84,030
G4	TMG	+	NH_3	→	TMG:NH_3				2.28×10^{34}	−8.31	3115
G5	TMG	+	NH_3	→	DMG:NH_2	+	CH_4		1.70×10^{4}	2	19,969
G6	DMG	+	NH_3	→	DMG:NH_3				4.08×10^{31}	−7.03	3234
G7	DMG	+	NH_3	→	MMG:NH_2	+	CH_4		5.30×10^{5}	1.56	20,744
G8	MMG	+	NH_3	→	MMG:NH_3				7.95×10^{24}	−5.21	2094
G9	MMG	+	NH_3	→	$GaNH_2$	+	CH_4		8.10×10^{5}	1.3	17,722
G10	NH_3	+	CH_3	→	NH_2	+	CH_4		3.31×10^{3}	2.51	9859
G11	CH_3	+	H_2	→	CH_4	+	H		1.20×10^{12}	0	12,518
G12	TMG	+	H	→	DMG	+	CH_4		5.00×10^{13}	0	10,036
G13	DMG	+	H	→	MMG	+	CH_4		5.00×10^{13}	0	10,036
G14	TMG:NH_3	→	MMG	+	$2CH_3$	+	NH_3		1.33×10^{44}	−8.24	77,791
G15	CH_3	+	H	+	M	→	CH_4	+	NH_3	2.40×10^{22}	−1	0
G16	$2CH_3$	=	C_2H_6							2.00×10^{13}	0	0
G17	2H	+	M	=	H_2	+	M			2.00×10^{16}	0	0

TMG, NH_3 & N_2/H_2/ARGON

Surface phase Reactions: PATH 1

	Path 1, $k = AT^n e^{-Ea/RT}$						A	n	E_a
1	MMG	+	N(S)	→	MMG(S)		1.16×10^5	2.98	0
2	MMG(S)	→	MMG	+	N(S)		1.12×10^{14}	0.55	107,673
3	NH_3	+	MMG(S)	→	COMPM1(S)		3.35×10^7	3.33	0
4	COMPM1(S)	→	NH_3	+	MMG(S)		5.70×10^{13}	−0.16	8146
5	MMG	+	COMPM1(S)	→	CH4	+ COMPM2(S)	1.23×10^{10}	3.22	23,446
6	NH_3	+	COMPM2(S)	→	COMPM3(S)		3.35×10^7	3.33	0
7	COMPM3(S)	→	NH_3	+	COMPM2(S)		5.70×10^{13}	−0.161	8146
8	MMG	+	COMPM3(S)	→	CH_4	+ COMPM4(S)	1.23×10^{10}	3.22	23,446
9	NH_3	+	COMPM4(S)	→	COMPM5(S)		3.35×10^7	3.33	0
10	COMPM5(S)	→	NH_3	+	COMPM4(S)		5.70×10^{13}	−0.161	8146
11	COMPM5(S)	→	CH4	+	RINGM1(S)		1.23×10^7	3.22	23,446
12	Ga(S)	+	RINGM1(S)	→	RINGM2(S)	+ N(S)	3.35×10^7	3.33	0
13	RINGM2(S)	→	$3H_2$	+	3GaN(B)	+ Ga(S)	3.68×10^9	2.05	59,610

TMG, NH_3 & N_2/H_2/ARGON

Surface phase Reactions: PATH 2

						Path 2, $k = AT^n e^{-Ea/RT}$	A	n	E_a
14	CH_3	+	Ga(S)	→	MMG(S)		1.76×10^9	1.39	0
15	MMG(S)	→	CH_3	+	Ga(S)		4.54×10^{13}	0.0346	79,480
16	NH_2	+	Ga(S)	→	NH_2(S)		3.17×10^8	1.83	0
17	$GaNH_2$	+	N(S)	→	$GaNH_2$(s)		2.27×10^6	2.247	0
18	$GaNH_2$(S)	→	$GaNH_2$	+	N(S)		4.83×10^{13}	0.614	83,881
19	COMPMM1(S)	→	CH_4	+	$GaNH_2$(S)		1.49×10^{11}	0.609	25,950
20	MMG	+	$GaNH_2$(S)	→	COMPMM1(S)		1.16×10^5	2.98	0
21	NH_3	+	COMPMM1(S)	→	COMPMM2(S)		3.35×10^7	3.33	0
22	COMPMM2(S)	→	CH_4	+	COMPMM3(S)		1.49×10^{11}	0.609	25,950
23	MMG	+	COMPMM3(S)	→	COMPMM4(S)		1.16×10^5	2.98	0
24	NH_3	+	COMPMM4(S)	→	COMPMM5(S)		3.35×10^7	3.33	0
25	COMPMM5(S)	→	CH_4	+	RINGM1(S)		1.49×10^{11}	0.609	25,950
26	NH_2(S)	→	NH_2	+	Ga(S)		1.45×10^{14}	0.09	59,786
27	COMPMM1(S)	→	MMG	+	$GaNH_2$(S)		1.00×10^{14}	0.55	42,819
28	COMPMM2(S)	→	NH_3	+	COMPMM1(S)		5.70×10^{13}	−0.1	8146
29	COMPMM4(S)	→	MMG	+	COMPMM3(S)		1.00×10^{14}	0.55	42,819
30	COMPMM5(S)	→	NH_3	+	COMPMM4(S)		5.70×10^{13}	−0.1	8146
31	Ga	+	N(S)	→	Ga(S)		1.00×10^{11}	1.5	0
32	Ga(S)	+	NH_2(S)	→	$GaNH_2$	+Ga(S)	1.00×10^{25}	0	0
33	Ga(S)	→	Ga	+	N(S)		1.00×10^{13}	0	45,168
34	$6CH_3$	+	RINGM2(S)	→	COM1(S)		7.55×10^7	2.31	0
35	COM1(S)	→	$6CH_3$	+	RINGM2(S)		1.00×10^{13}	0.71	45,506
36	COM1(S)	→	$6CH_4$	+	3GaN(B)	+Ga(S)	4.00×10^{12}	0	49,675

TMG, NH_3 & N_2/H_2/ARGON

Surface phase Reactions: PATH 3

								Path 3, $k = AT^n e^{-Ea/RT}$	A	n	E_a
37	TMG	+	N(S)	→	TMG(S)				1.16×10^5	2.98	0
38	NH_3	+	TMG(S)	→	TCOM1(S)				3.35×10^7	3.33	0
39	TCOM1(S)	→	CH_4	+	TCOM2(S)				1.49×10^{11}	0.609	32,785
40	Ga(S)	+	TCOM2(S)	→	TCOM3(S)	+	N(S)		3.35×10^7	3.33	0
41	TCOM3(S)	→	$2CH_4$	+	GaN(B)	+	Ga(S)		1.49×10^{11}	0.609	49,675
42	TMG(S)	→	TMG	+	N(S)				1.12×10^{14}	0.55	49,675
43	TCOM1(S)	→	NH_3	+	TMG(S)				5.70×10^{13}	−0.161	11,922
44	TMG:NH_3	+	N(S)	→	TCOM1(S)				1.16×10^5	2.98	0
45	TCOM1(S)	→	TMG:NH_3	+	N(S)				1.12×10^{14}	0.55	49,675
46	TCOM1(S)	→	$2CH_3$	+	MMG(S)	+	NH_3 +N(S)		1.12×10^{14}	0.55	10,7673
47	$MMGNH_3$	+	N(S)	→	COMPM1(S)				1.16×10^5	2.98	0
48	COMPM1(S)	→	MMG:NH_3	+	N(S)				1.12×10^{14}	0.55	107,673
49	MMG:NH_3	+	COMPM1(S)	→	CH_4	+	COMPM3(S)		1.23×10^{10}	3.22	23,446
50	MMG:NH_3	+	COMPM3(S)	→	CH_4	+	COMPM5(S)		1.23×10^{10}	3.22	23,446
51	MMG:NH_3	+	$GaNH_2$(S)	→	COMPMM2(S)				1.16×10^5	2.98	0
52	MMG:NH_3	+	COMPMM3(S)	→	COMPMM5(S)				1.16×10^5	2.98	0

METHODOLOGY: KMC

Total Deposition Rate:

$$R = A + H + D$$

A - Adsorption, H – Diffusion, D - Desorption rates

$A = Flw$ Here, l and w denote length and width of substrate

$h_j = D_0 exp\left(-\frac{E_j}{k_B T}\right)$ The characteristic vibration frequency , $D_0 = \frac{2k_B T}{h}$

$d_j = D_0 exp\left(-\frac{E_j^{des}}{k_B T}\right)$ with $E_j^{des} = E_S + nE_n$

EXTRACTABLE

1. Lattice Parameters:

- ❑ Layer by layer lattice parameter Extraction.
- ❑ Averaging layer by layer lattice constant may produce overall lattice constant of film.
- ❑ The lattice constant can be calibrated with lattice constant with XRD studies.
- ❑ Lattice constant includes all the strain, defects etc effects.

2. Strain:

- ❑ Averaging layer by layer strain produce overall strain in the film.
- ❑ The strain can be calibrated with experimental strain.

3. Surface Roughness:

- ❑ Extract surface roughness as a function of growth time

$$r = \sqrt{\frac{\sum_{i=1}^{N}\sum_{j=1}^{N}[h_{ij}-\bar{h}]^2}{NxN}}$$

Here N is the total number of lattice points, h_{ij} is the height at a given lattice point located at position *i* and *j*, on the lattice and h_{avg} is the average height of all lattice points.

4. Mole fraction:

- ❑ Extract number of atoms of different constituents layer by layer.
- ❑ Ratio of group-III & V deposited atoms ➡ Molefraction.

5. Defects :

- ❑ Extract number of interstitials, vacancy etc layer by layer along with dislocation and Stacking Faults

Case Study : **Si/AlN** Planetary MOCVD Process

INPUT CONDITIONS

Parameters	Si/AlN	Pre-Nitridated Si/AlN
Chamber Temperature (°C)	300	300
Chamber Pressure (mbar)	40	40
Chamber Volume (lits)	1.4	1.4
Ceiling Height (cm)	1	1
Substrate Temperature (°C)	1050	1050
Precursors	TMAl & NH_3	TMAl & NH_3
Precursors Flow Rate (sccm)	105 sccm & 1 slm	105 sccm & 1 slm
Carrier Gas	H_2	H_2
PreNitridation(slm)	-	1

Parameters	Si/AlN	Pre-Nitridated Si/AlN
Nitridation Temperature (C)	-	1050
Nitridation Time (s)	-	30
Surface Energy (eV)	2.0	2.0
Desorption Barrier (eV)	3.0	3.0
Schwoebel Barrier (eV)	0.05	0.05
Incorporation Barrier (eV)	0.05	0.05
Nearest Neighbour (eV)	0.05	0.05
No. of Interactive Elements	1	1
Substrate Dimension (A^2)	50x50 [Unit Cell]^2	

CHEMICAL KINETICS

Gas Phase Equations

Al(CH3)3 = AlCH3 + 2CH3 ,	A=3.5*10^15,	n=0,	Ea= 66500
Al(CH3)3 + NH3 = Al(CH3)3:NH3 ,	A=3.0*10^12	n=0	Ea= 0.0
Al(CH3)3:NH3 = Al(CH3)3 + NH3 ,	A=5.0*10^10	n=0	Ea= 22000
Al(CH3)3:NH3 = (CH3)2Al:NH2 + CH4 ,	A=2.0*10^12	n=0	Ea= 27000
Al(CH3)3:NH3 + NH3 = (CH3)2Al:NH2 + CH4 + NH3 ,	A=2.0*10^12	n=0	Ea= 13000
2(CH3)2Al:NH2 = ((CH3)2Al:NH2)2 ,	A=4.0*10^11	n=0	Ea= 0.0

##Gas to Surface Phase Equations

Al(CH3)3 + space = Al(S) + 3CH3 , coll 1.0

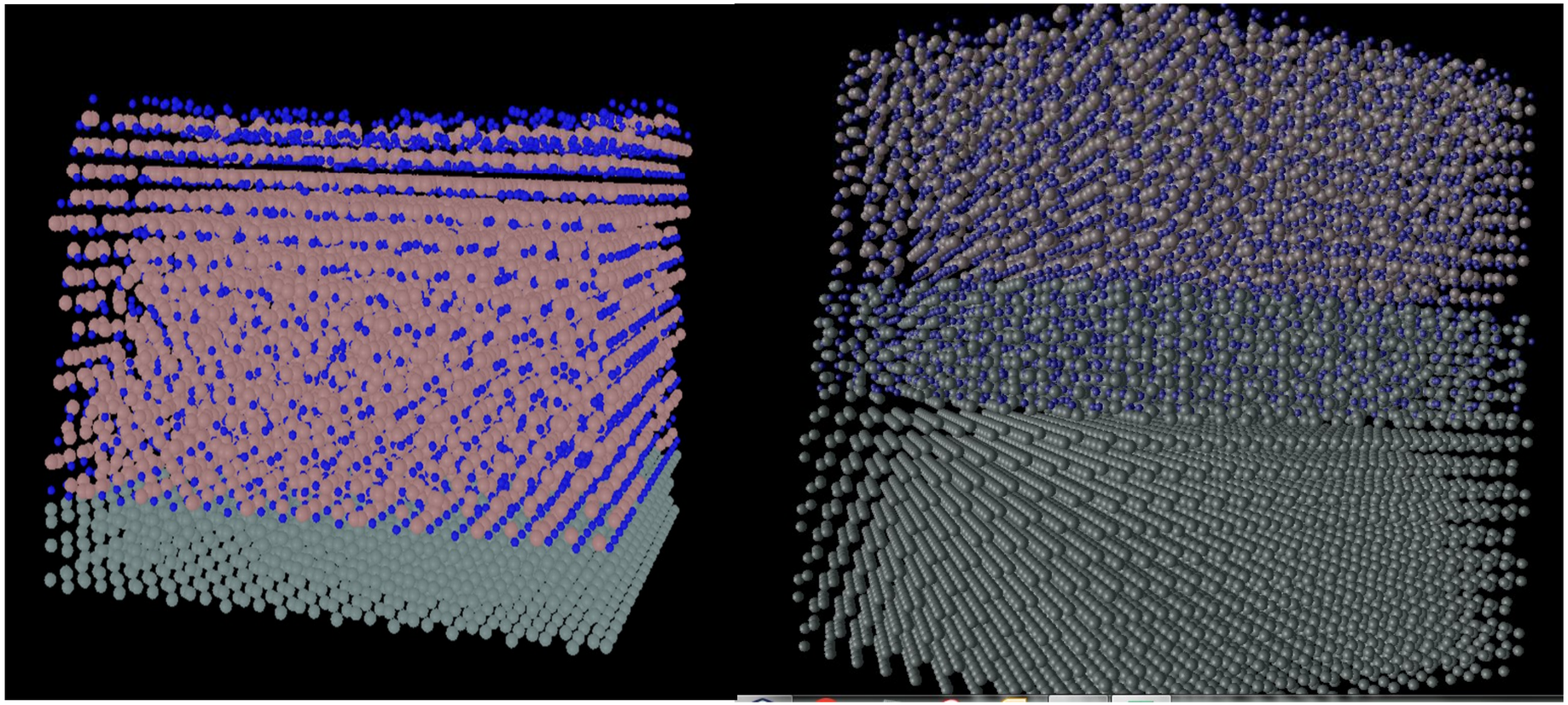
Al(CH3)3:NH3 + space = Al(S) + 3CH3 + NH3 , coll 1.0

AlCH3 + space = Al(S) + CH3 , coll 1.0

(CH3)2Al:NH2 + space = AlN(S) + 2CH4 , coll 1.0

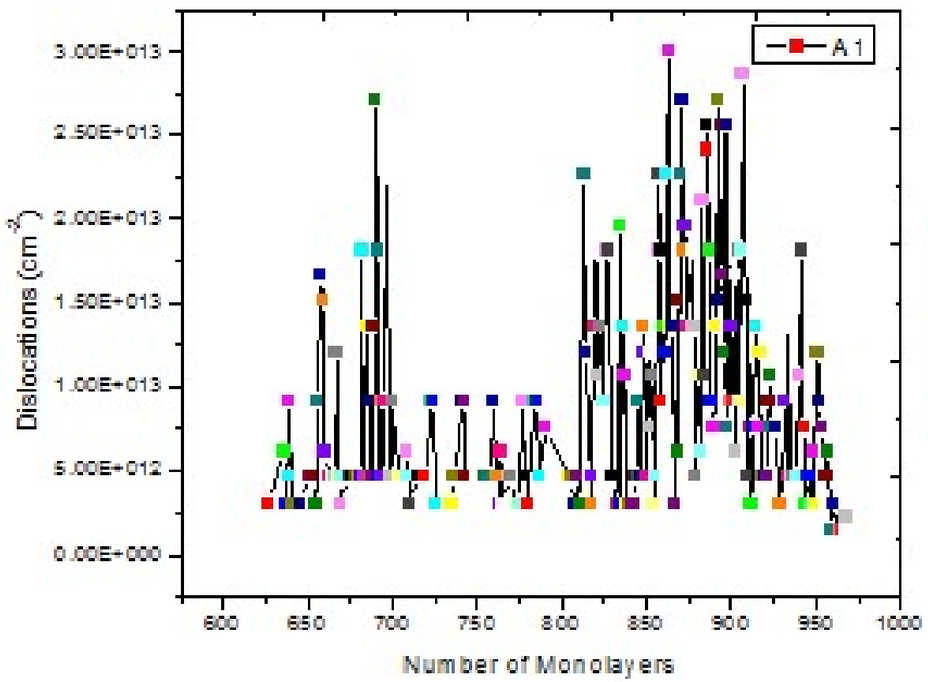
((CH3)2Al:NH2)2 + space = 2AlN(S) + 4CH4 , coll 1.0

OUTPUT

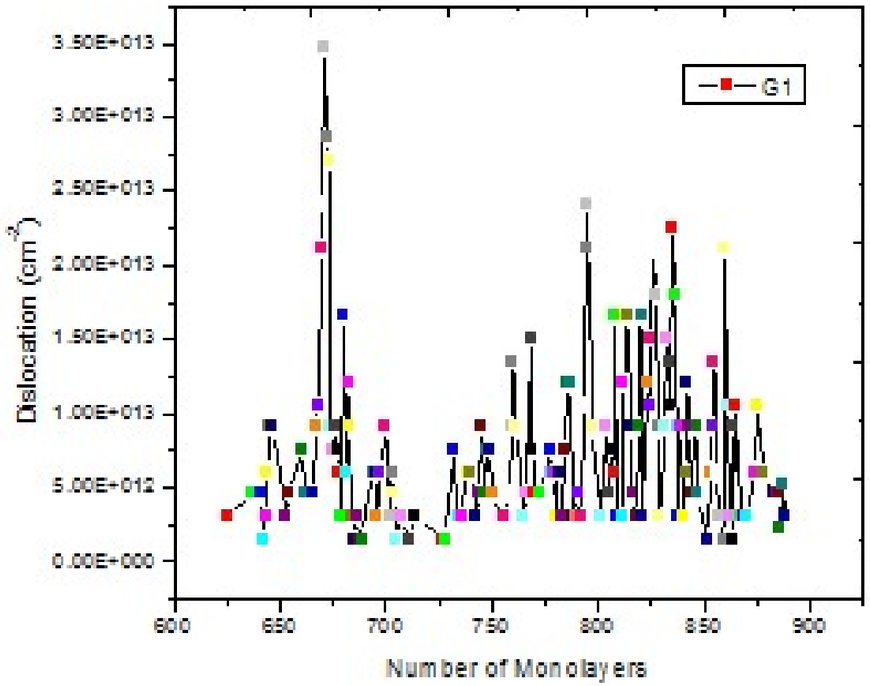


Without Nitridation **Pre-Nitridation for 30 s**

Dislocations Per Monolayer

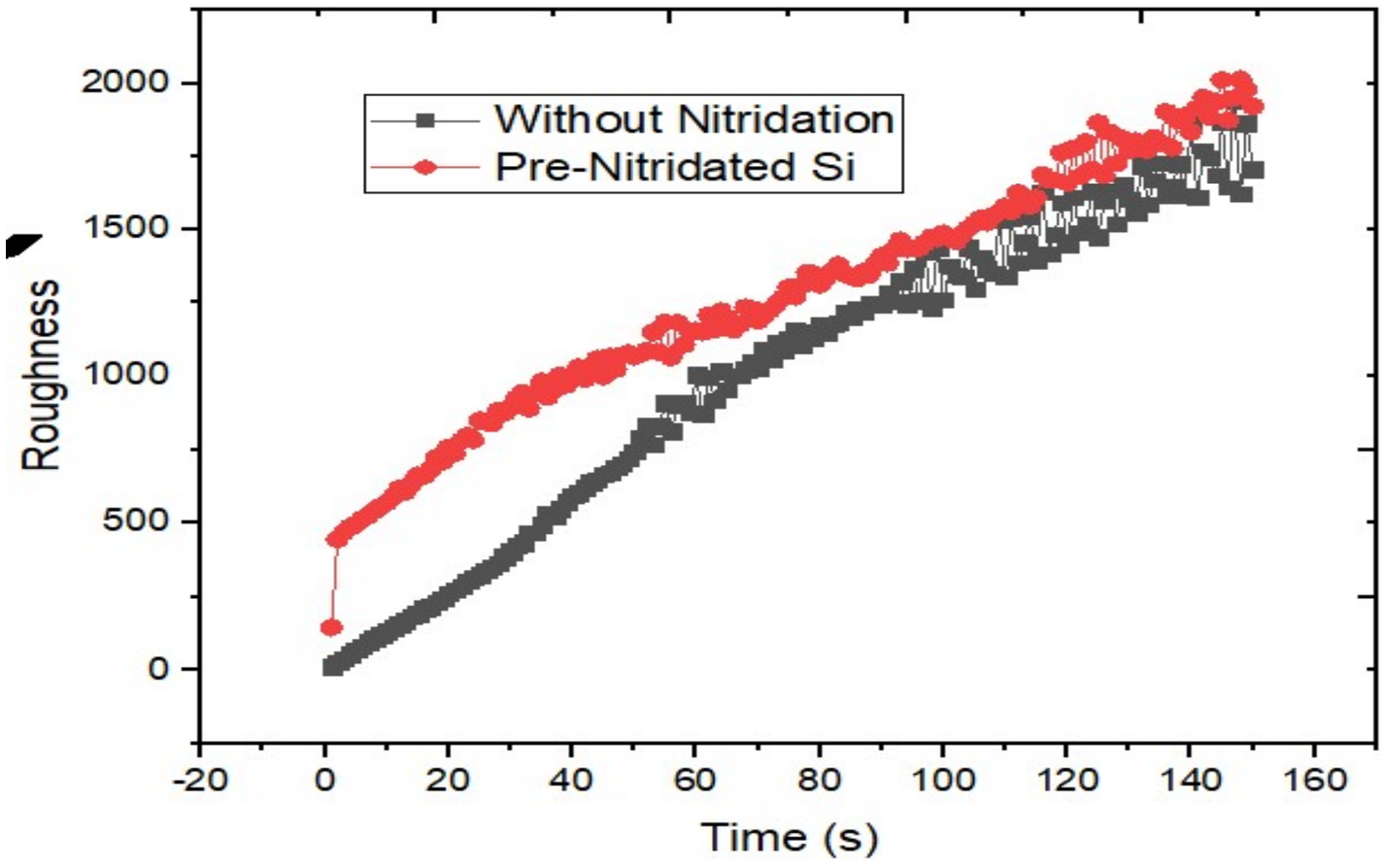


Without Nitridation



Pre-Nitridation for 30 s

Surface Roughness



Other Output

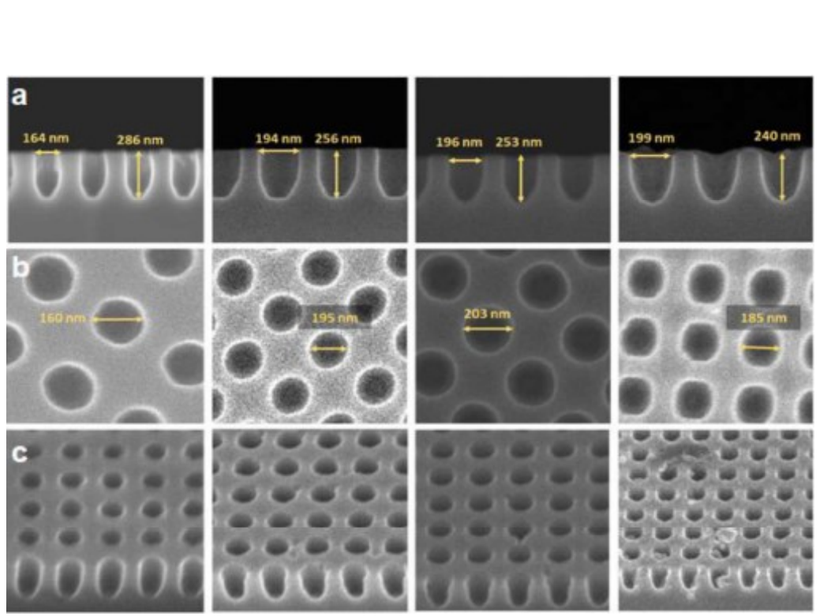
Parameters	Si/AlN	Pre-Nitridated Si /AlN
Substrate Thickness (µm)	0.3258	0.3258
Si3N4 Thickness (nm)	-	3.7817
Total Deposited Atoms (AlN)	5046178	5233815
Vacancies (cm^{-3})	36069	13393
Total Dislocation Density (cm^{-3})	2503	1612
Al Atoms	≈50%	≈50%
N Atoms	≈50%	≈50%
Many More ……		

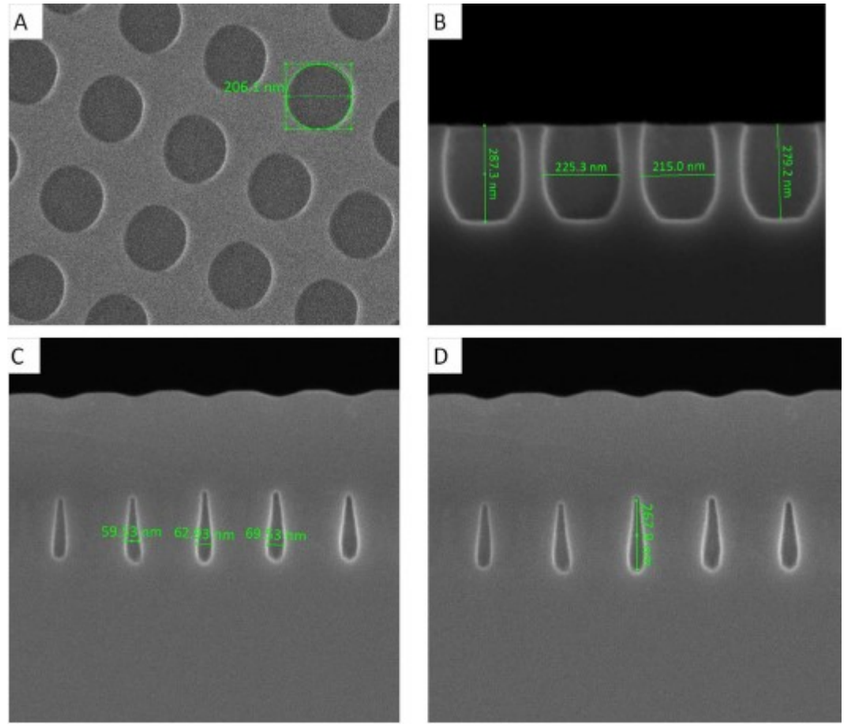
Patterned Substrate: Selective Epitaxy

TNL-Injector Simulator provides flexibilities to simulate regrowth processes at Atomistic Scale for Selective Epitaxy with capabilities:

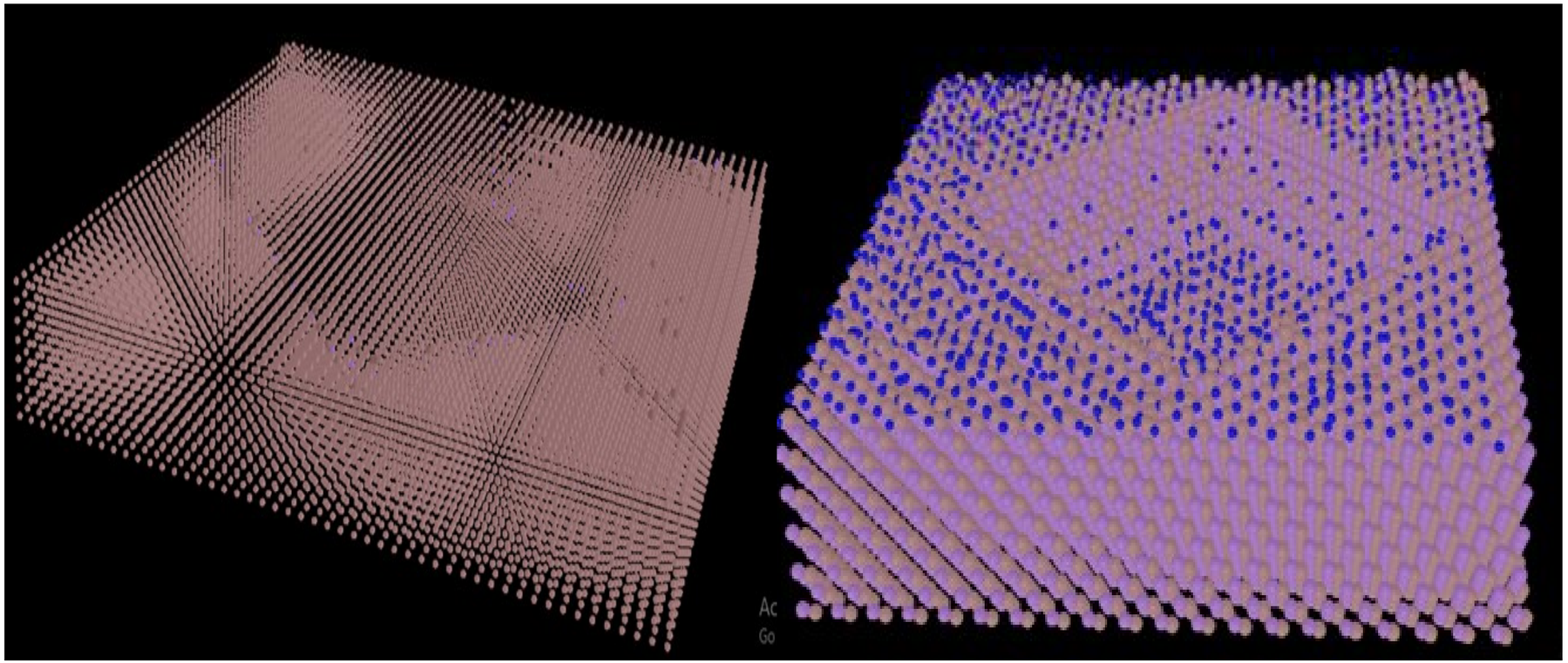
- *Process* Optimization
- Atomistic growth process for void-semiconductor photonic crystal (PhC)
- Better understanding of invisible *Physical Phenomenon*
- *Patterned substrates Shapes: Steps, Grooves, Well etc.*
- *Epitaxial growth through: MBE, MOVPE/MOCVD*
- *Effects of regrowth on **air-hole morphology***
- Comparison between patterned substrate hole regrown void's dimensions
- patterned substrate hole: *play a very critical role in the final regrowth*
- *Many More Benefits ….*

MAJOR CHALLENGES: DIMENSIONS OF AIR HOLE





Re-growth over Step Patterned Substrate



Regrowth of Si over GaAs Step Pattern Substrate Unit Cells representation

Regrowth of Si over GaAs Step Pattern Substrate Atomistic representation

ADVANCE LICENSING & PRICE VALUE

TNL's tools support advanced and unique licensing models tailored for unique customer needs.

➢ ADVANCED LICENSING OPTIONS:

- Term-Based
- Perpetual with Annual Maintenance Cost (AMC)
- TCAD Academic Suite
- 24x7 Technical Support for **Academic Institutions**

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Thank You

Contact us

+91-983-915-1284

info@techNextlab.com

Lucknow 226 003, INDIA

www.technextlab.com