UCLA ENGINEERING
Henry Samueli School of Engineering and Applied Science
Electrical Engineering Department

Device Research Laboratory

Quasi van der Waals epitaxy of GaAs on graphene/Si by molecular beam epitaxy

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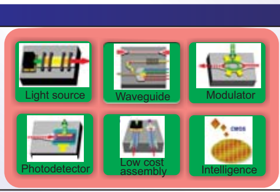
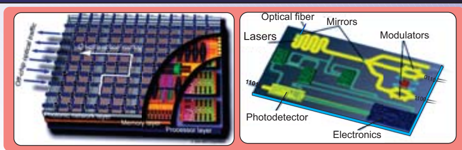
Motivation





Source: Silicon Integrated Nanophotonics at IBM

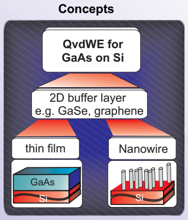
Integration of GaAs wireless devices/lasers on Si

- → Enabling direct high-speed on-chip communication
- → Optical interconnect
- → Overcoming GaAs on Si mismatches and reducing defect densities.

Perkin-Elmer Molecular Beam Epitaxy

Quasi-van der Waals epitaxy (QvdWE)

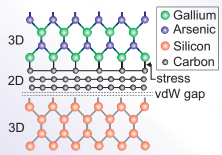
Concepts



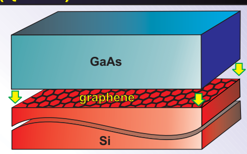
Challenges

(1) Due to low surface energy, so deposited GaAs films will tend not to wet the buffer surface, resulting in island growth

(2) Al, Ga, In, As atoms for the AlGaInAs material system exhibit very low adsorption and migration energies on graphene

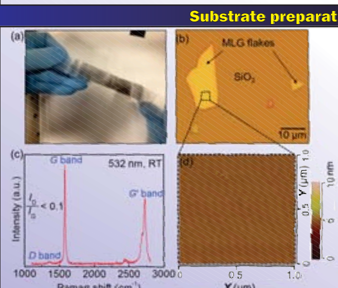


Atomic geometry of GaAs/multi-layer graphene/Si



schematic view for a structure with GaAs grown on graphene/Si

Substrate preparation



a) Mechanical exfoliation of multi-layer graphene (MLG) flakes using scotch-tape.

(b) optical microscope image of MLG.

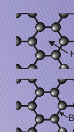
(c) Raman spectrum for exfoliated MLG.

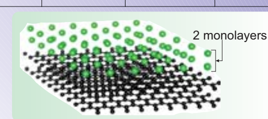
(d) AFM image of the exfoliated MLG on SiO_2/Si showing an ultra-smooth surface morphology in the dashed square box.

Theoretical investigations

III-V atoms on graphene

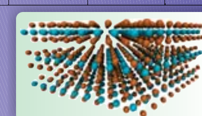
Atoms	Adsorption Site	Adsorption Energy (eV)	Migration Energy (eV)
Ga	H	1.5	0.05
Al	H	1.7	0.03
In	H	1.3	0.06
As	B	1.3	0.21





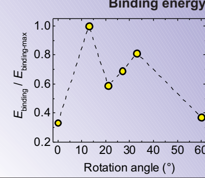
III-V atoms on other vdW materials, such MoS_2 and BN

Atom	Adsorption Energy 1L h-BN (meV/atom)	2L h-BN (meV/atom)	1L-MoS_2 (meV/atom)
Ga	131.6 (T)	134.3 (T)	234.6 (T)
Al	135.1 (T)	101.1 (T)	237.4 (T)
In	66.9 (B)	85.1 (T)	573.1 (T)
As	296.9 (B)	341.5 (T)	527.8 (T)



Atomic arrangement of MoS_2

Binding energy vs rotation angle



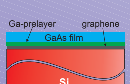
Binding energy calculations show the perfectly oriented GaAs/graphene interface is not the minimum energy configuration

Van-der-Waal interactions accounted for self-consistently in calculations

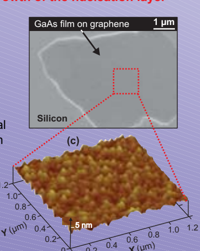
Epitaxial growth and characterization

GaAs Growth on Ga-terminated graphene

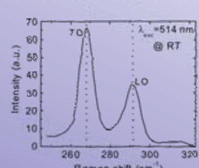
Low-temperature growth of the nucleation layer



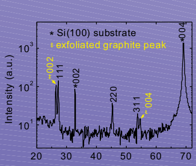
schematic cross-sectional view of GaAs films grown with Ga-prelayer on multilayer-graphene/Si



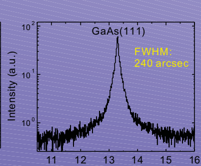
SEM and AFM images, showing the surface morphology



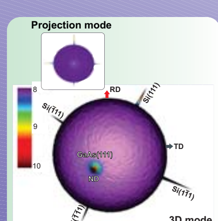
Raman spectrum of the nucleation layer



θ–2θ scan, showing multiple non-coplanar reflections

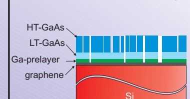


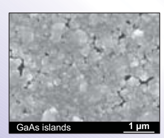
XRD rocking-curve scan of 111 peak



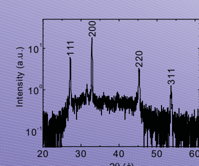
Pole figure of the 111-textured film

GaAs deposition on graphene via two-step growth



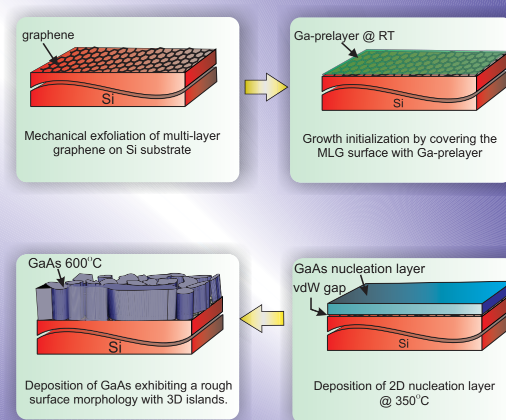


SEM image of 200 nm high-temperature GaAs on a 25-nm-thick nucleation layer, with Ga-prelayer showing a 3D cluster growth which could be caused by the elevated temperature during the second step growth



θ–2θ scan, showing polycrystallinity with the presence omultiple non-coplanar reflections

Growth model of GaAs on Si via QvdWE



Mechanical exfoliation of multi-layer graphene on Si substrate

Growth initialization by covering the MLG surface with Ga-prelayer

Deposition of 2D nucleation layer @ 350°C

Deposition of GaAs exhibiting a rough surface morphology with 3D islands.

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