Energy Release Rate of Quantum Islands in Stranski-Kratanow Growth

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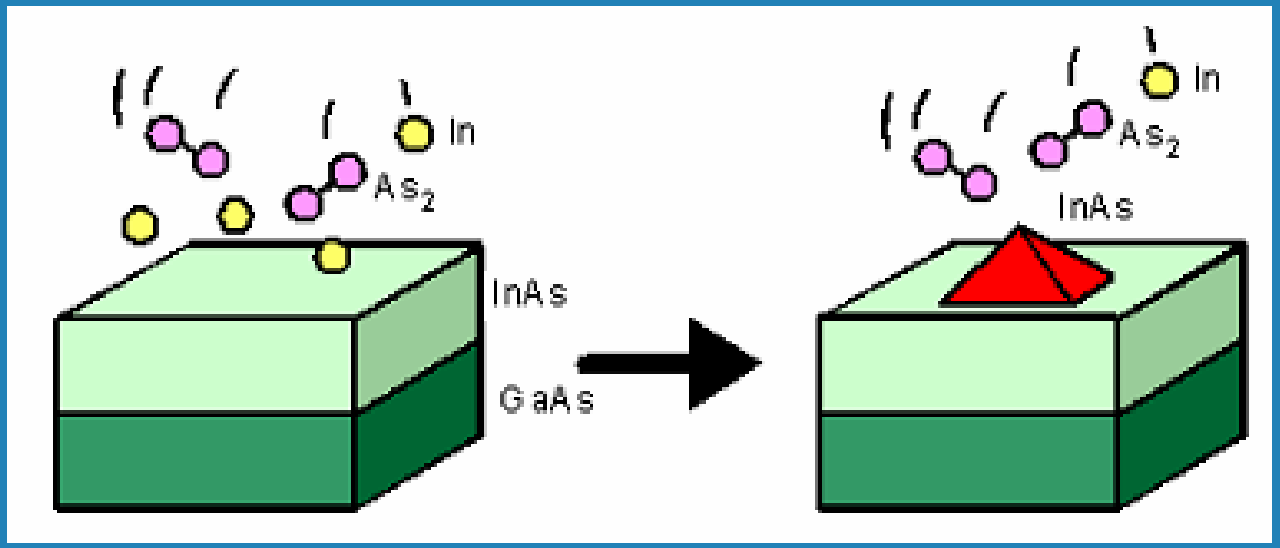
Outline

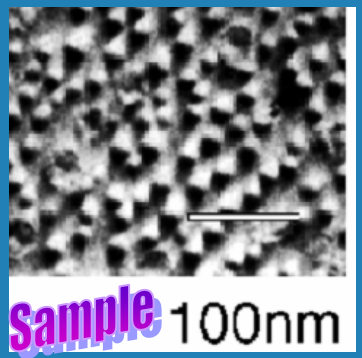
- Self Assembly of Quantum Wires/Dots in Heteroepitaxy
- Energy Release Rate

  Vs. Local Strain Energy Density
- Simulations
- Conclusions
- Future Works

Self-Assembly of QIs

A misfit-strain-energy driven instability!!!

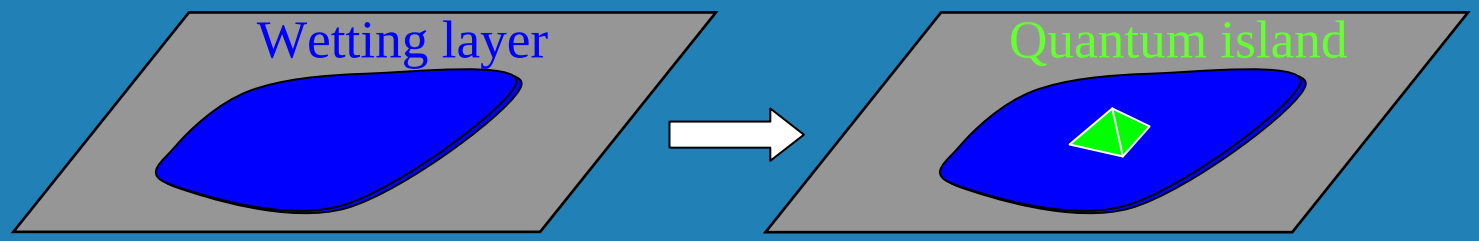




Heteroepitaxy

Kinetics vs. Thermodynamics?

Energetics of QI Self-Assembly



Spontaneous process: $\Delta E / \Delta t < 0$

$$\Delta E = \Delta\left(\int_V e_{elastic} dV\right) + \Delta\left(\int_S e_{surface} dS\right) + \Delta\left(\int_L e_{edge} dL\right)$$

$$-\frac{\Delta}{\Delta t}\left(\int_V e_{elastic} dV\right) > \frac{\Delta}{\Delta t}\left(\int_S e_{surface} dS\right) + \frac{\Delta}{\Delta t}\left(\int_L e_{edge} dL\right)$$

Energy Release Rate of QI Self-Assembly

Definition of EERR:

$$\Gamma \equiv -\frac{dW}{dV_{mt}}, \text{ where } W = \int_V e_{elastic} dV$$

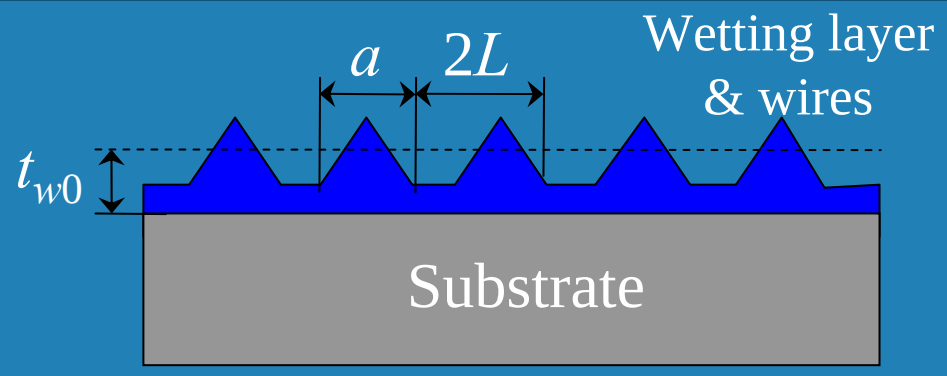
Criterion of QD Nucleation:

$$\Gamma \geq \Gamma_{NC}$$

Rate of QD Growth:

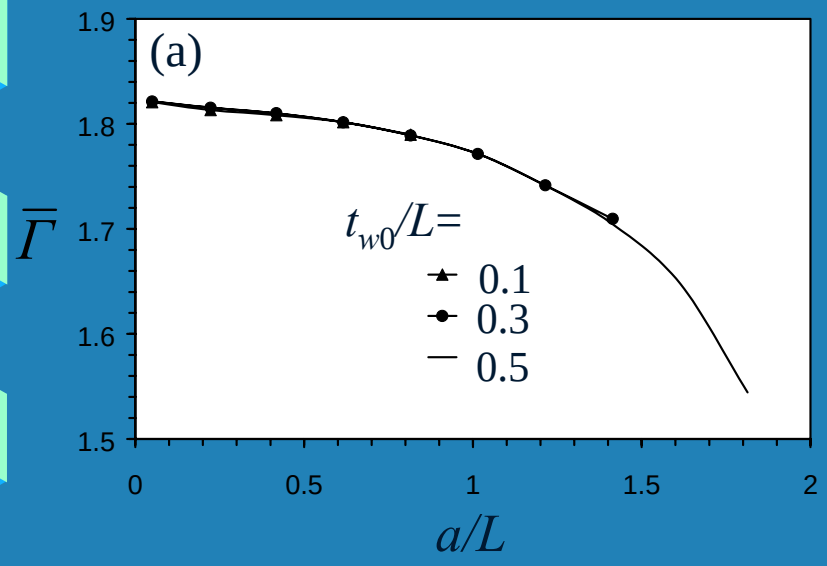
$$\frac{dV_{mt}}{dt} = Ae^{B(\Gamma - D)}$$

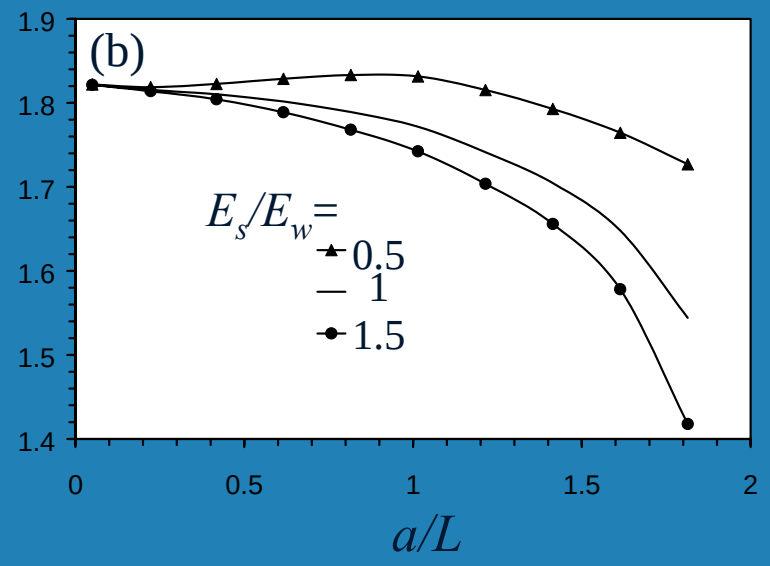
QW Growth in an Epilayer-Substrate System



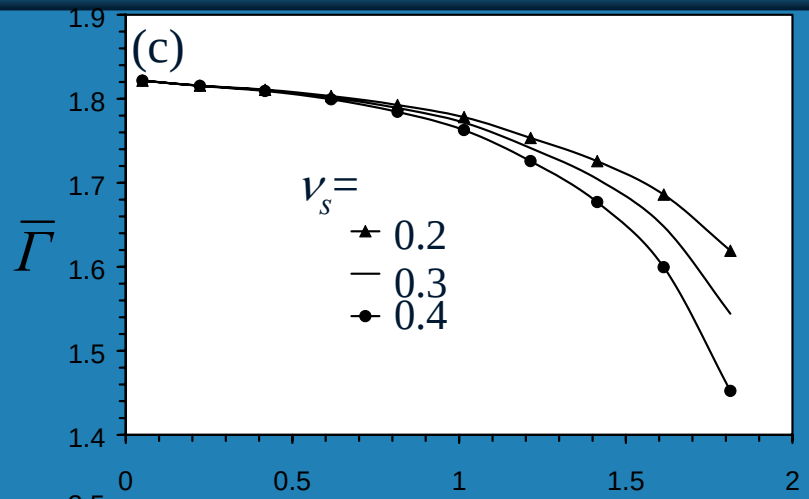
t_{w0}, θ, ν_w, E_s, ν_s

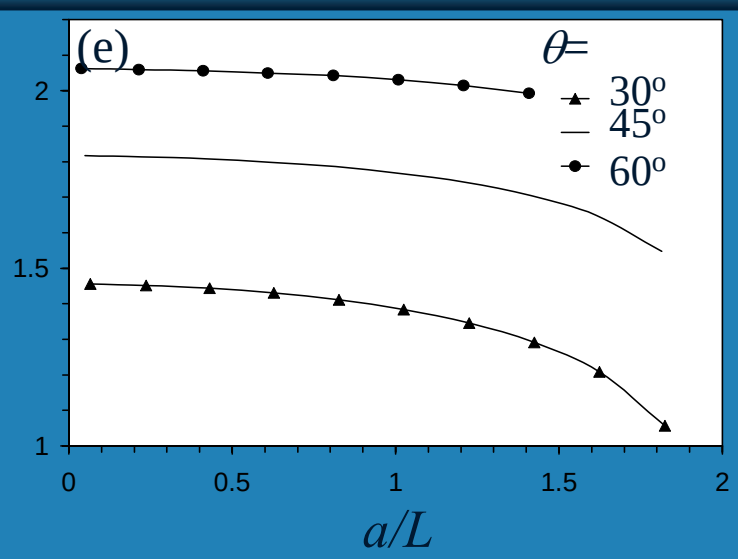
L, E_w

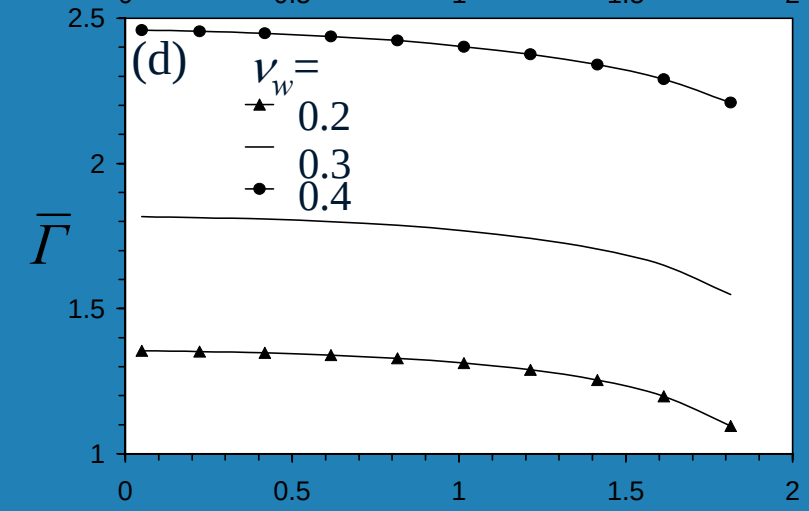




QW Growth in an Epilayer-Substrate System (contd)



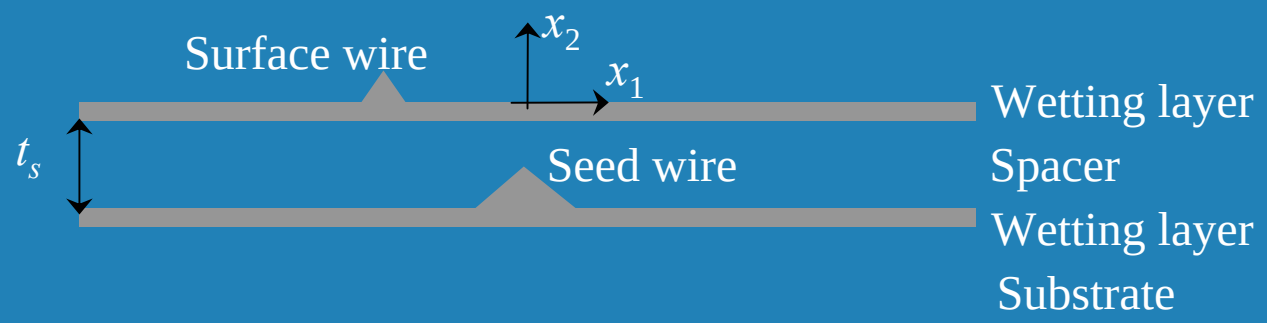


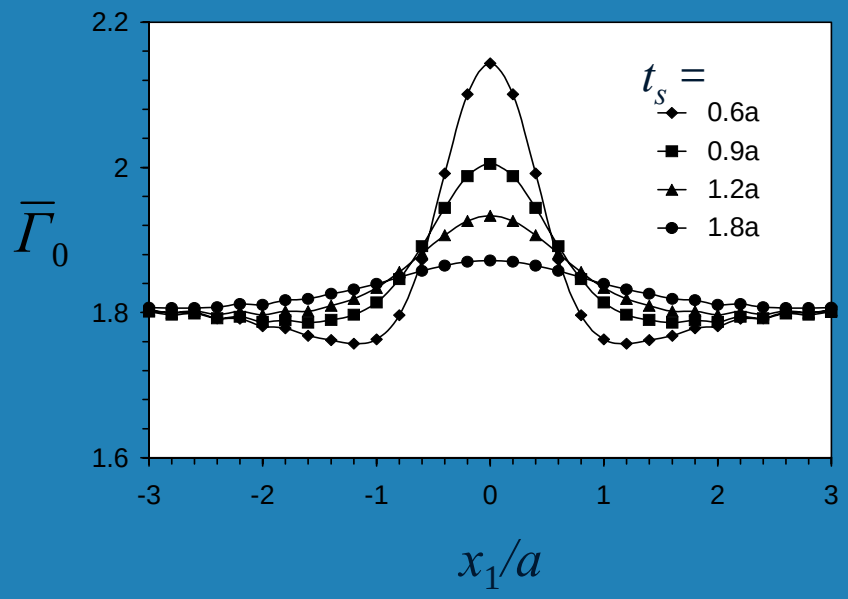


EERR Expansion:

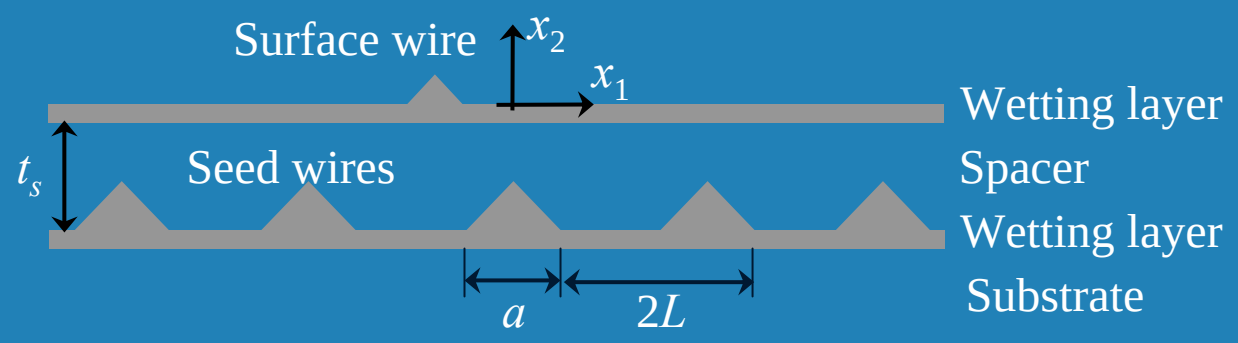
$$\bar{\Gamma} = \frac{\Gamma}{E_w(\varepsilon^0)^2} = \bar{\Gamma}_0(\nu_w, \theta) + \frac{a}{L}\bar{\Gamma}_1\left(E_s, \nu_s, \frac{a}{L}\right)$$

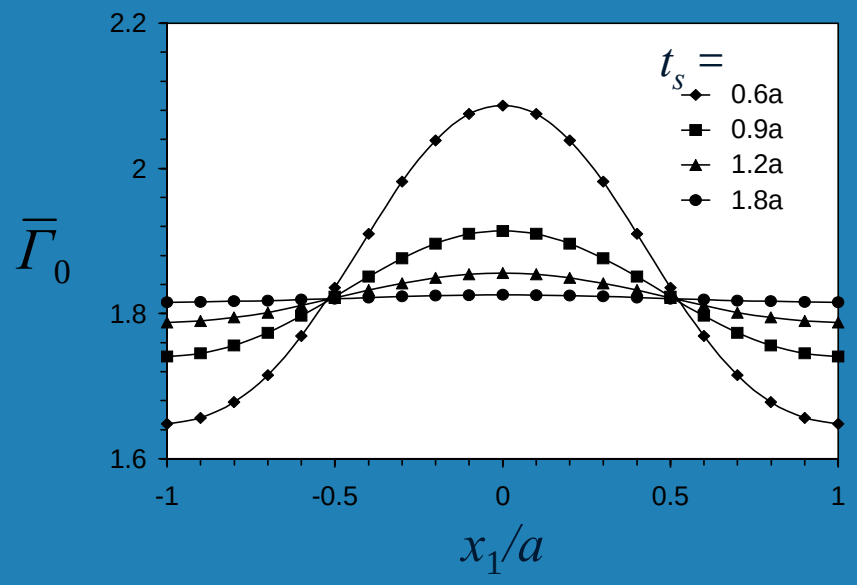
Vertical Correlation of QWs: Dilute Seed QWs



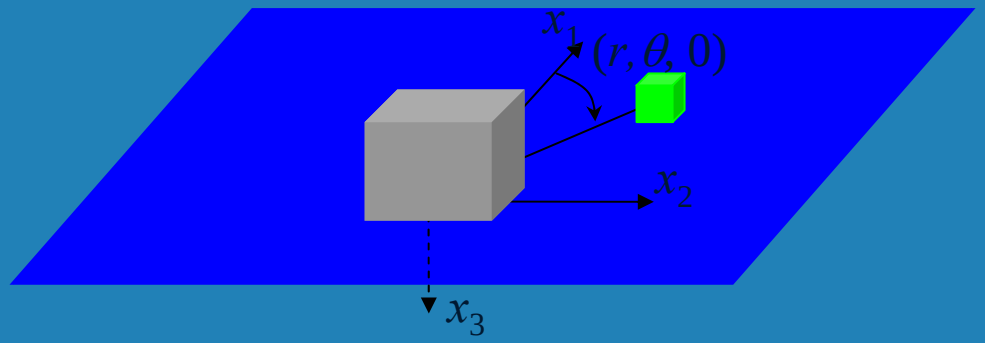


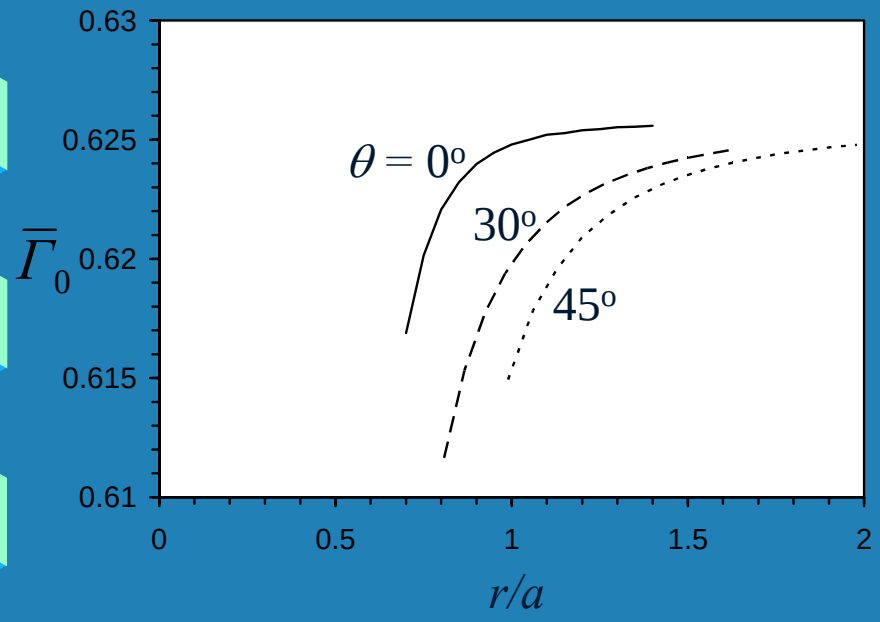
Vertical Correlation of QWs: Dense Seed QWs

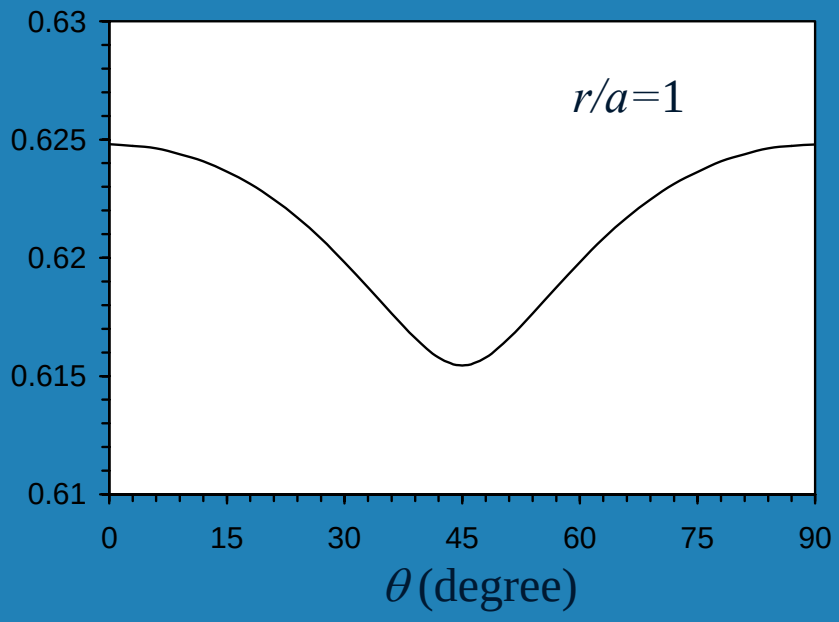




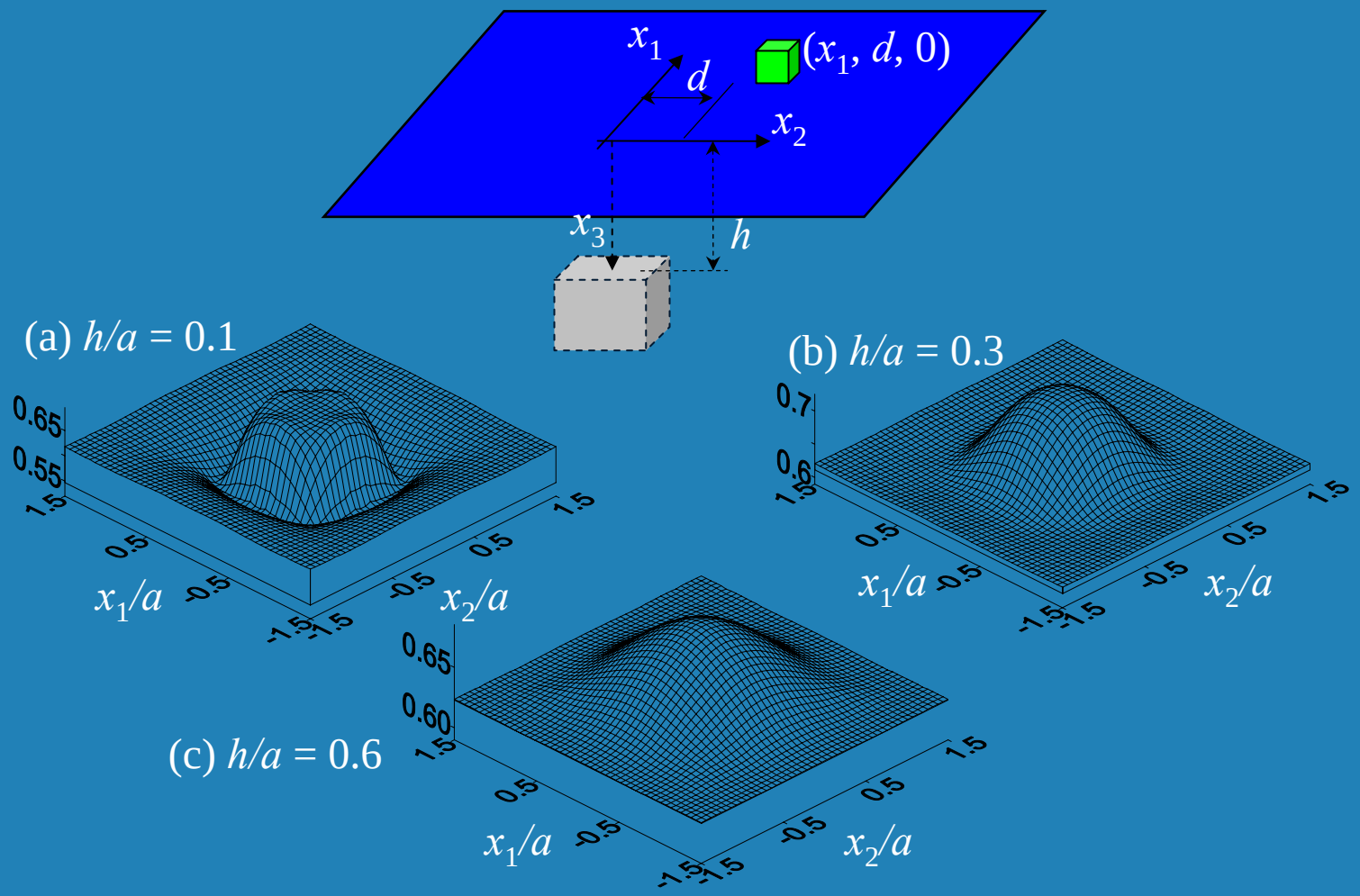
Nucleation of a QD near a Laterally Neighboring QD



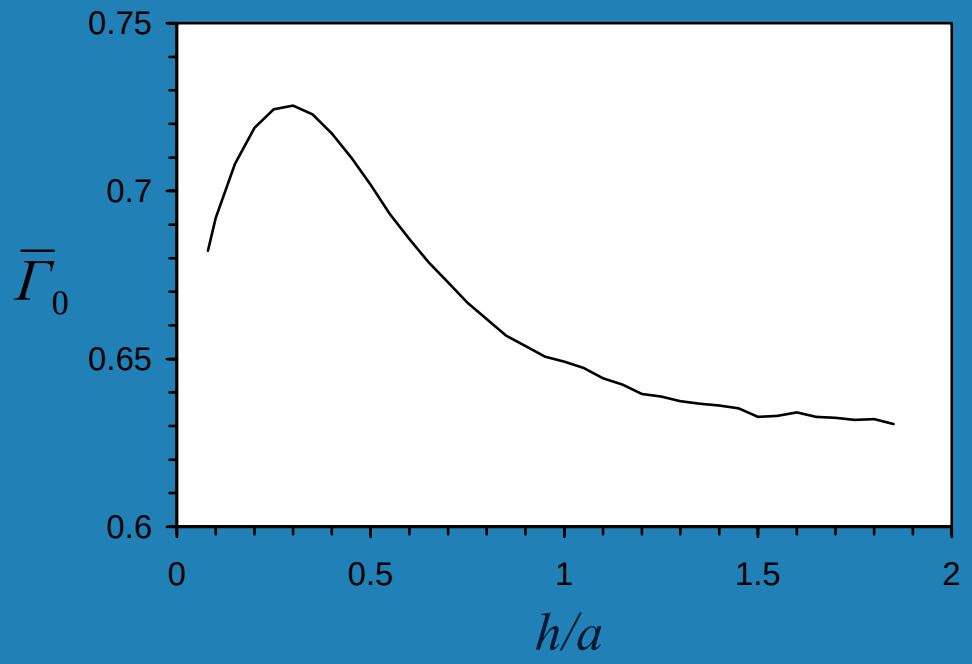




Nucleation of a QD near a Vertically Neighboring QD



Optimal Depth of a Buried QD for Nucleation of a New QD



Conclusions

- We have proposed the parameter of EERR to quantify the driving force for QI self-assembly towards a *quantitative* prediction of the critical events such as nucleation and a *quantitative* description of the growth process.
- We have examined the EERR of QW growth in an epilayer-substrate system. We found that a new surface QW is correlated to a buried QW in both dilute and dense systems.
- We have examined the nucleation of a QD near laterally and vertically neighboring QDs applying the EERR. Not only the favorable location but also the amplitude of EERR variation are predicted that lead to better understanding of the interaction of neighboring QDs.

Future Works

- Mechanical Characterization
- Strain analysis (elastic, piezoelectric, magnetoelastic, etc.)
- Energetics of QD formation
- Stability of QDs arrays (ripening, rearrangement, etc.)
- Defect mechanics & dynamics around and within QDs (dislocations, vacancies, interstitials, substitutions)
- Diffusion between QDs and matrix