The Physics of Locally Controlled Strain Fields

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Abstract

Using a fabrication process known as mesotaxy, we can control the surface distribution of strain and thereby the self assembled growth of nanostructures such as quantum dots. By limiting the effects on localization of growth to the strain parameter, we also seek to learn more about the formation of self organized nanostructures.

Methods

What is mesotaxy?

- High dose ion implantation (~10^{17} ions/cm^2)
- High temperature anneal (~1000 °C)
- Buried layer or inclusion production
  - Controlled dimensions and structure

Why mesotaxy?

Buried layers

↓

Lattice mismatch

↓

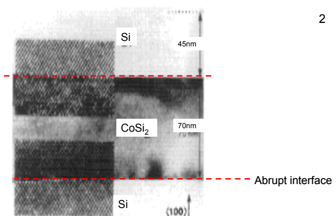
Buried strain

↓

Surface strain field

↓

Affects epitaxial growth



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Cross section TEM micrograph of a buried CoSi2 layer in (100) Si. Insets (left) are of HREM images of upper and lower interfaces.

By changing the surface strain field, we can control the nucleation of quantum dots, which will grow in such a way as to minimize the surface strain energy of the system. We can model the surface strain field by: 3

$$\varepsilon(x,y) = \frac{C}{(x^2+y^2+L^2)^{\frac{3}{2}}}\left(\frac{3L^2}{(x^2+y^2+L^2)}-1\right)$$

Where L is the depth of the inclusions, x and y are distances in the surface plane from a point on the surface above the inclusion and C is a constant (for point sources).

Quantum Dots

What is a quantum dot?

A nanoscopic structure confining a small, countable number of electrons to a region that is smaller than the de Broglie wavelength. Also called artificial atoms and single electron transistiors in some incarnations.

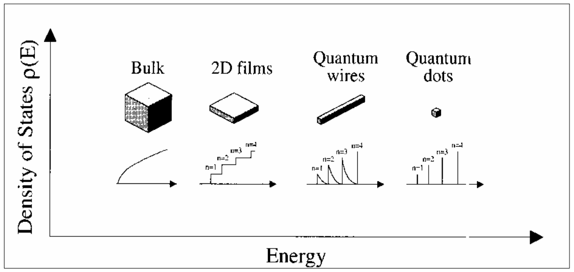
Why are we interested in quantum dots?

Quantum dots are excellent model systems for testing low-dimensional theories and have numerous applications, including:

- Semiconductor lasers
- Photosensors
- Single electron transistors
- Quantum Cellular Automata – quantum computing
- Biological sensors and taggants

What are the properties of a quantum dot?

- Discretized energy levels
  - Single electron manipulation
  - Precise, tunable emission lines
- High density of states
- Quantum confinement of carriers
- Radiative recombination efficiency increased
- Non-radiative recombination efficiency decreased



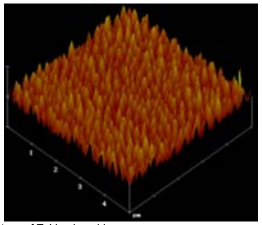
Why use mesotaxy?

- Current systems → 1:1 or random individual nucleation → slow process
- Need a 1:n, self organized process
  Rapid, accurate, repeatable
  CMOS process compatible

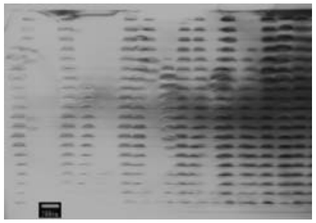
Self organized undirected growth

Pros:
Short range order
Short range size uniformity

Cons:
No long range order
Random placement
Size variations



AFM image courtesy of T. Vandervelde



Quantum dot superlattice showing 20 layers of stacked quantum dots.

TEM Image courtesy of T. Vandervelde.

The quantum dot superlattice shows us that we can use buried strain fields to control the surface strain and the nucleation of subsequent layers of quantum dots

Future Directions

- Transport studies
  - Buried dots and layers
  - Dot arrays
  - Uses as fabrication and interconnect tools

References

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