A study on the nucleation of ferromagnetic MnSb crystallites on a GaAs (001) surface

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III-V compound semiconductors are key materials for semiconductor lasers, while ferromagnetic compounds can be used for controlling the propagation of a laser beam. Thus, both types of materials are essential for optoelectronic applications, but integrating the two is difficult due to their different crystal structures and chemical properties. If they can be grown together in a single form, one can expect a better efficiency of optical communications and lower production costs. Here, we study the growth of ferromagnetic MnSb on GaAs. Knowing that nucleation is essential in the crystal growth process and the ultimate way of crystal growth is to control its nucleation process, we are trying to control the nucleation of MnSb for producing high-quality ferromagnetic thin films. We first grow MnSb thin films on GaAs substrates using molecular beam epitaxy under ultra-high vacuum and proper temperatures and beam fluxes; and then utilize tools such as *in-situ* reflection high-energy electron diffraction (RHEED), *ex-situ* scanning electron microscopy, and ex-situ X-ray diffraction to extract information on the forms of nucleation, crystal growth orientation, and lattice parameters of MnSb. So far the orientation of MnSb crystallites is determined to be <10-11>MnSb normal to a GaAs (001) surface. Moreover, analysis of a RHEED pattern along the [1-10] GaAs direction seems to show a dynamic change of the lattice constant of MnSb as a function of growth time. Further analysis and conclusions will be made by the time of this presentation.

The Nucleation of MnSb on the GaAs Surface

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Summary

Semiconductors are desired for optical electronics, while ferromagnetic materials are ideal for laser isolators. The difficulty to combine the two is due to their different crystal forms. We attempt to grow ferromagnetic MnSb onto semiconductor GaAs using Molecular Beam Epitaxy (MBE) and study the nucleation process of MnSb during the growth process.

Terms

MBE (Molecular Beam Epitaxy)

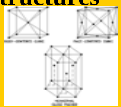
- Main Chamber
- Transfer Chamber
- Entry Chamber

MBE Machine

Growth Chamber

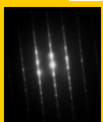
GaAs and MnSb Crystal structures

- GaAs: Face-centered cubic
- MnSb: Hexagonal



Electron Diffraction

- Newton's Ring
- Bragg's Law:



Electron Diffraction

Newton's Ring

n*lambda = 2d sin (theta)

- Single-crystal:
  - Very smooth: one bright spot
  - Little rough: clear streaks plus spots
  - Very rough: ring patterns
- Poly-crystal: unclear patterns

Reciprocal Lattice

- Definition: *Each family of lattice planes (hkl) is associated with a point g, also identified by (hkl), whose distance from the origin of the coordinate system equals 1/d and which is located on the normal to the lattice planes (hkl).*
- G (hkl) = 1/d(hkl)

Procedure

Temperature

Growth Chamber: -196 Degree Celsius (N2 is used for cooling)

Pressure

- Growth Chamber: 10^(-10) Torr (760 Torr = 1 atm)
- Mn: 2.2x10^(-8) Torr
- Sb: 7~8x10^(-8) Torr

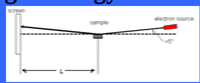
Growth Rate

Growth rate = 1 monolayer/second

Tests

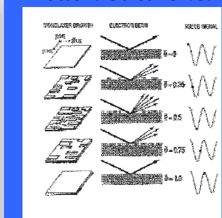
RHEED (Reflection High-Energy Electron Diffraction)

- RHEED Gun + Screen

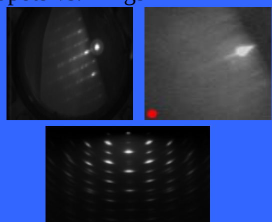


RHEED Gun Illustration

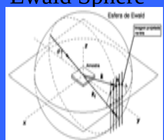
- Electron Beam angle =2 Degrees
- Reflection of Crystal Growth Condition
- Patten: Streaks vs. Spots vs. Rings



Growth Condition vs. RHEED Signal



- Ewald Sphere



3D Illustration of electron diffraction

- **X-ray Diffraction**
- Indication of growth orientation
- Three Variants: alpha, beta, thai

Scanning Electron Microscopy

- Up to 50 nanometers

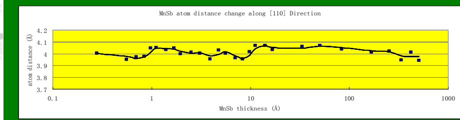
Results

Plane Orientation of Crystal Growth

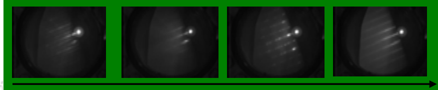
- <10-11>MnSb normal to a GaAs (001) surface

MnSb atom distance change during Growth

1. [110] Direction

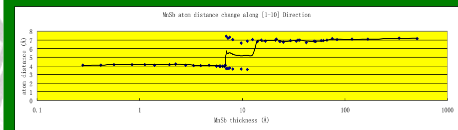


2. [110] Direction RHEED Illustrations



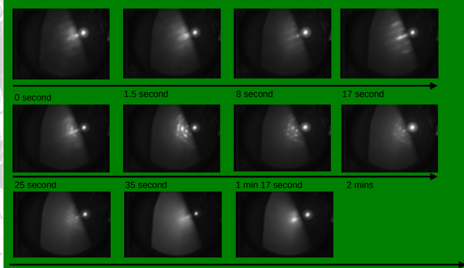
0 second | 4 second | 40 second | 20 mins

3. [1-10] Direction



1 second => 1 Monolayer => 0.28 Å

4. [1-10] Direction RHEED Illustrations



0 second | 1.5 second | 8 second | 17 second
25 second | 35 second | 1 min 17 second | 2 mins
3 mins 5 second | 5 mins | 30 mins

Conclusion

Our experiments shows that the orientation of MnSb crystal growth on GaAs is <10-11>MnSb normal to a GaAs (001) surface. RHEED patterns along the [110] GaAs direction indicates a relatively stable atom distance of MnSb, while the ones along the [1-10] GaAs direction shows a dynamic change of the MnSb atom distance along with the MnSb thickness. Moreover, unclear patterns between 30s and 1min 30s along the [1-10] GaAs direction is suspected to indicate poly-crystal structures.

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