Pulsed Laser Deposition (PLD)

Physical Vapour Deposition Techniques
and
High temperature Superconductors

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Summary

• why study superconductors?
• thin film vs bulk synthesis
• issues to consider in film growth:
  – stoichiometry, epitaxy, impurities, strain, “second phases”
• types of thin film synthesis
• pulsed laser ablation
• example: the grain boundary problem in YBaCuO
12.5 kV, 1250 Amp, 3 phase High temperature superconducting cable

Why superconductors? Why PLD?

YBa$_2$Cu$_3$O$_{7-x}$ crystal structure showing Cu coordination.

RF superconducting filter for cell phone base stations.
Bulk vs. thin film synthesis

**Flux-grown YBCO bicrystal**
- simple growth
- very good stoichiometry
- very good crystallinity
- difficulty in controlling structure

**PLD-grown YBCO bicrystal**
- growth in a vacuum chamber
- can control stoichiometry
- can control crystallinity
- well-defined final structure.
Thin film growth techniques

- evaporation/ MBE
- sputtering
- pulsed laser deposition
- CVD (chemical vapour deposition)

- electrochemical
- sol-gel
- spin-coating
- spray pyrolysis

\{ vacuum
\quad - one step epitaxy
\}

\{ “bulk” techniques
\quad - post-anneal needed for epitaxy
\}
Film growth issues:

1. **Stoichiometry**: chemical composition of the film.

2. **Epitaxy**: the film is single crystal, and is related to the substrate crystal orientation. Achieved by heating the substrate, so the film atoms have energy to relax into a crystal structure commensurate with the substrate.

3. **Impurities**: at high temperatures, the substrate and film atoms can interdiffuse. Other impurity sources: target holders, walls etc.

4. **Strain**: the crystal spacing of film and substrate material is usually not the same. This means the film has intrinsic strain, which can lead to defects, film roughness, delamination.

5. **Second phases**: the film may phase-separate into different regions, with different properties.
1. Island growth (Volmer - Weber)
• form three dimensional islands
• film atoms more strongly bound to each other than to substrate
• and/or slow diffusion

2. Layer by layer growth (Frank - van der Merwe)
• generally highest crystalline quality
• film atoms more strongly bound to substrate than to each other
• and/or fast diffusion

3. Mixed growth (Stranski - Krastanov)
• initially layer by layer, then forms three dimensional islands
Each target atomic species has its own “effusion cell”.

Each type of target is vaporized independently by i) heat, ii) e-beam, iii) laser.

Rate control is the big challenge.

UHV MBE system for GaAs etc.
A sputtering gas is used to excite a charged plasma which coats the substrate. Each type of atom has a different sputtering energy. Controlling the charged plasma, and preventing resputtering from the substrate are the challenges here.
YBa$_2$Cu$_3$O$_{7-x}$ films on SrTiO$_3$ substrates.

A high-power excimer laser is focused on the target.

The target is ablated to form a plume of atoms, molecules and “chunks”.

The advantage of PLD is that complex materials can be easily ablated.
The challenge is minimizing “chunks”, and maintaining stoichiometry.
Laser + optics

gas handling

chamber

PVD Laser deposition system
Advantages and Disadvantages of PLD

Advantages:
1. New technique.
2. Simple (fast, and easiest to study new chemical systems).
3. Compatible with oxygen and other reactive gases.

Disadvantages:
1. Particulates.
2. Composition and thickness depend on deposition conditions. Difficult scale-up to large wafers?
Goal: Understanding electromagnetic transport across low angle grain boundaries (LAGBs).

In YBa$_2$Cu$_3$O$_{7-x}$ bicrystals, the zero field $J_c$ across the grain boundary drops rapidly with misorientation angle, $\theta$.

*Dimos, Chaudhari, Mannhart, LeGoues, PRL, 61, 219 (1988); PRB, 41, 4038 (1990).*

What do PLD grown films look like?

FESEM image of $7^\circ \text{YBa}_2\text{Cu}_3\text{O}_7$

HRTEM image of $10^\circ \text{YBa}_2\text{Cu}_3\text{O}_7$
High magnetic field, nV sensitive transport data show progressive change with $\theta$

Log($V$) - log($I$) show increasing GB influence, at low and high voltage, as $\theta$ increases.

77 K, H||c
Different 7° thin film bicrystals can have very different extended V-I characteristics.

![Graph showing V-I characteristics for different bicrystals.]

In one bicrystal, there is little evidence of the GB in the V-I characteristic. The other bicrystal shows evidence of weak coupling and flux flow along the GB at higher V.
• Low angle [001] tilt YBa$_2$Cu$_3$O$_{7-x}$ bicrystals were grown by laser ablation, and characterized by FESEM, TEM, and zero and high magnetic field transport.

• A progression from strongly coupled, flux-pinning limited transport behavior to weakly coupled, Josephson behavior was seen between 3° and 15°.

• Variation between bicrystals with the same θ shows that extrinsic factors modify the GB transition region.
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