Highly Efficient Preparation of Double-sided YBCO thin films with MOCVD

Bowan Tao, Ruipeng Zhao and Yudong Xia

2023-10-31
Technical background

Double-sided YBCO thin films on crystal substrate with MOCVD

Double-sided YBCO coated conductor with MOCVD

Conclusion
01 Technical background
1. YBCO thin films performance

- $T_c \sim 90 \text{ K}$
- $R_S(10\text{GHz}, 77\text{K}) < 1\text{m}\Omega$
- $J_C(77\text{K}, 0\text{T}) \sim 1-5 \text{ MA/cm}^2$

Liquid nitrogen temperature  
Low microwave surface resistance  
High critical current density
2. Application of YBCO thin films

- **Microelectronic devices**
  - Low Rs, Strong anti-interference
  - Low loss and high sensitivity
  - Deposited on single crystal

- **Coated conductors**
  - High filed, high Jc
  - Mechanical properties
  - Deposited on flexible substrate

**Demand:**
- Large area, double sided thin films
- High efficient preparation, doping other elements

**Thickness:**
- Hundreds of nanometers
- Several micrometers
3. Why double sided structure?

- For Microelectronic devices
  - Graphics
  - Advantage of Filter
    - Lower insertion loss
    - Smaller bandwidth
    - Sharp edge steepness

- For coated conductors
  - Double sided structure
  - One sided structure

Substrate polish – double sided
Protective layer – double sided
Buffer and YBCO layer – single sided

Can we make all double sided structure?

Same thickness
- Double current
- Smaller volume
- Lower cost of cooling

Same current
- Half of YBCO thickness
- Easier to prepare
- Lower Lorentz force

Which technology suitable for large scale preparation of YBCO films/conductors?
4-1、YBCO deposited technology-Sputtering (UESTC)

Low deposition rate, 50nm/h
Small scale 1 sample 2inch.
4-2. YBCO deposited technology - Evaporation (Ceraco)

High deposition rate 20 - 30 nm/min.

Large scale 12 samples 2inch.

One sided deposition
More vacuum time
4-3. YBCO deposited technology-PLD(SLAB)

Middle deposition rate 6.7 nm/min.
small scale 1 sample 2inch.

One sided deposition
More vacuum time
4-4, YBCO deposited technology-MOD (estimate)

Low deposition rate 1~3 nm/min.
Small scale 1 sample 2inch.

Double sided deposition
No vacuum time
4-5. YBCO deposited technology-MOCVD (UESTC)

High deposition rate 20~30 nm/min.
Large scale 12×2 inch or 6×3 inch.

Double sided deposition
Short vacuum time
4-6、YBCO deposited technology-compare

<table>
<thead>
<tr>
<th>Technology</th>
<th>Deposition rate (nm/min)</th>
<th>Deposition area</th>
<th>Vacuum</th>
<th>Equipment investment</th>
<th>Cost of materials</th>
<th>Large scale</th>
<th>Double sided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation</td>
<td>20-30</td>
<td>large</td>
<td>high</td>
<td>high</td>
<td>low</td>
<td>easy</td>
<td>No</td>
</tr>
<tr>
<td>PLD</td>
<td>6-30</td>
<td>small</td>
<td>high</td>
<td>high</td>
<td>middle</td>
<td>hard</td>
<td>No</td>
</tr>
<tr>
<td>Sputtering</td>
<td>~1</td>
<td>large</td>
<td>high</td>
<td>middle</td>
<td>middle</td>
<td>hard</td>
<td>YES</td>
</tr>
<tr>
<td>MOD</td>
<td>1-3</td>
<td>large</td>
<td>none</td>
<td>low</td>
<td>low</td>
<td>hard</td>
<td>YES</td>
</tr>
<tr>
<td>MOCVD</td>
<td>20-60</td>
<td>large</td>
<td>low</td>
<td>middle</td>
<td>high</td>
<td>easy</td>
<td>YES</td>
</tr>
</tbody>
</table>

MOCVD May be a better choice for YBCO deposition
02 Double-sided YBCO thin films on crystal substrate with MOCVD
1. MOCVD deposited double sided YBCO thin films

<table>
<thead>
<tr>
<th>Sub.</th>
<th>Lattice (nm)</th>
<th>Misfit to YBCO (%)</th>
<th>ε</th>
<th>tanδ</th>
</tr>
</thead>
<tbody>
<tr>
<td>LaAlO₃</td>
<td>0.3788</td>
<td>-2.7</td>
<td>24</td>
<td>&lt;5 × 10⁻⁴</td>
</tr>
<tr>
<td>SrTiO₃</td>
<td>0.3905</td>
<td>2.2</td>
<td>1900</td>
<td>3 × 10⁻²</td>
</tr>
<tr>
<td>MgO</td>
<td>0.4212</td>
<td>8.55</td>
<td>9.6</td>
<td>4 × 10⁻⁵</td>
</tr>
<tr>
<td>YSZ</td>
<td>0.516</td>
<td>6.2</td>
<td>25</td>
<td>7.5 × 10⁻³</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>a=0.4763, c=1.3</td>
<td>23.6</td>
<td>9.5-11</td>
<td>1.5 × 10⁻⁶</td>
</tr>
</tbody>
</table>

- LaAlO₃ substrate small misfit
- LaAlO₃ suitable for microwave device
- LaAlO₃ substrate easy to recycle

schematic diagram of MOCVD system
2、Optimization of deposition parameter on LAO substrate

- **Deposition temperature**
  - Impure phase
  - a axis
  - c axis
  - Decompose

- **O₂ flow**
  - Impure phase
  - Small grain
  - Dense films

- **840°C**

- **1000 sccm**
2. **Optimization of deposition parameter on LAO substrate**

The growth evolvement diagram of YBCO film morphology with composition changes.

\[ \frac{1}{2} Y_2 O_3 – BaO – CuO \] ternary phase diagram. \( J_c \) and \( R_s \) distribution depending on the film composition marked with various colors.

**Surface and \( J_c \) ternary phase diagram**

- 1. desert
- 2. groove
- 3. pore
- 4. dense film
- 5. small outgrowth
- 6. large outgrowth

\[
\begin{align*}
\text{Ba : Y} & = 1.3-1.5; \\
\text{Ba : Cu} & = 0.56-0.61
\end{align*}
\]
3. MOCVD results of YBCO films

- 2inch thickness deviation ± 3%
- 500nm thickness deviation ± 10%
- Forming a stable production process flow

Ellipsometer results

Rs < 0.5 mΩ
Jc > 2 MA/cm²
Filter fabrication for verification of the YBCO films
4. MOCVD deposition 3inch double sided YBCO thin films

Equipment improvement: deposited 3 inch YBCO films
03 Double-sided YBCO coated conductor with MOCVD
1、Challenge of double-sided coated conductor

- Protect back side surface when double sided deposition?
- Keep double-sided consistency?
- Achieve long tapes preparation?
- Achieve high performance?

- Which technology be choose? (buffer and YBCO)
- How to heat the double-sided structure?
- How to reel to reel the long tapes
- Biaxial texture, surface roughness and flux pinning?

- Fully independent reel to reel system
- Deposition of double-sided simultaneous
- Constant speed and tension in reel to reel system
- Substrate self heating technology

We need all the layers with double-sided structure!
2. SDP technology for deposition of $\text{Y}_2\text{O}_3$ layer

- Double-sided deposition of $\text{Y}_2\text{O}_3$ as isolating layer
- Increase stability of the solution (10 hours to several days)
- Keep solution concentration (solution concentration drop to 40% to almost unchanged)
- Long tapes preparation (100 m to 500 m)
2、SDP technology for deposition of Y_{2}O_{3} layer

**500m results:**

- **A side**
  - $RMS_{\text{min}} = 0.46$ nm,
  - $RMS_{\text{max}} = 0.66$ nm,
  - $RMS_{\text{avg.}} = 0.55$ nm

- **B side**
  - $RMS_{\text{min}} = 0.48$ nm,
  - $RMS_{\text{max}} = 0.66$ nm,
  - $RMS_{\text{avg.}} = 0.55$ nm

SDP system and samples
3. IBAD technology for deposition of MgO films with Auto flipping

**Double-sided R to R system:** Deposition of double-sided simultaneous

**Back sided protection:** protect the back side for cleaning

**Advantage:**
- Reduce process (vacuum) steps
- Reduce atmospheric exposure
- Improve double-sided consistency
3、IBAD technology for deposition of MgO films with Auto flipping

Double-sided IBAD-RHEED
Epi-MgO-XRD omega and phi scan

Traditional structure double-sided FWHM of omega and phi
Advanced structure
Consistency are better than traditional system
4. Medium frequency reactive sputtering for deposition of LMO

- High R to R speed (50 m/h)
- Two metal target for double-sided deposition

\[ \Delta \omega = 2-3^\circ, \ \Delta \Phi = 3-4^\circ \]

\[ R_{\text{rms}} = 1.6 \text{ nm} \]
5、MOCVD for YBCO coated conductor deposition

- **Self heating system** was used for double-sided deposition
- Shower is very closed to tapes for Mo source utilization
- The self heating technology have **Very high heating efficiency**
- The self heating technology have **Very high heating speed**

- 700 W/m, about 850°C
- No other heater
- Tradition heater need 5 kW/m
5、MOCVD for YBCO coated conductor deposition

- multilayer films of ReBCO films
- 77K、0T，single side $I_c = 328$ A/cm

Photo of MOCVD system deposited YBCO coated conductors
5. MOCVD for YBCO coated conductor deposition

TEM results of the YBCO coated conductor with self heating system

Compare with MgO single crystal
6、Developing a narrow channel chamber to improve the utilization of Mo source

Narrow channel chamber, utilization of MO source > 31%

![Diagram of narrow channel chamber]
7. **Improvement structure of Narrow channel chamber**

**New Narrow channel chamber MOCVD system**
8. Results of different position of narrow channel chamber

ΔFWHM(Δω)<0.2°
ΔFWHM(Δφ)<0.5°

Significant improvement in consistency of thickness and Jc performance
9. Double sided results of YBCO coated conductors

$I_c \approx 327 \text{ A/cm-width}$

$J_c \approx 3.2 \text{ MA/cm}^2$ (~1000 nm)

Double sided results is very closed,
04 Conclusion
Conclusion

For Thin films
1. Developed a double-sided deposition MOCVD system
2. Achieved high uniformity double-sided YBCO thin films

For coated conductors
1. Developed a fully double-sided structure for coated conductors
2. One-time experiment with single-source single-ion beam finish the preparation of double-sided IBAD-MgO seed layers
3. A new narrow channel chamber has been developed for improving the utilization of MO source
Thank you!