THU-PO3-617-05

Optimal operating conditions of $YBa_2Cu_3O_y$ HTS diode with a $PrBa_2Cu_3O_y$ buffer layer

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Introduction

- Superconducting diode

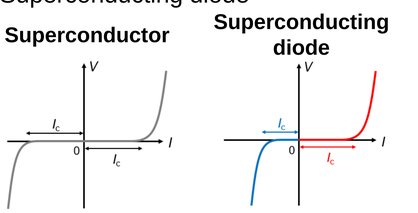
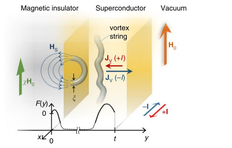
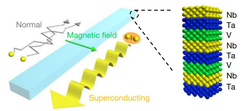


Fig. *I-V* characteristics of superconductor(left) and superconducting diode(right)

✓ Asymmetric *I* -*V* characteristics
✓ Different I_c depending on the current direction



J. Lustikova *et al.*: Nat. Commun. **9**, 4922 (2018).



F. Ando, *et al.*: Nat. **584**.7821 (2020).

- Future application

Wireless-power-transfer superconducting magnet

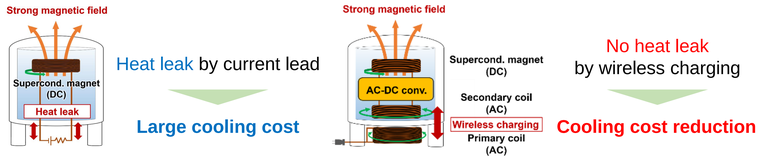


Fig. Schematic of conventional superconducting magnet

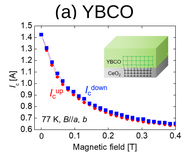
Fig. Schematic of wireless power transfer superconducting magnet

Objective

To investigate the optimal operating conditions of the $YBa_2Cu_3O_y$ superconducting diode films toward the wireless-power-transfer superconducting magnet.

Results & Discussion

- Field dependence of I_c



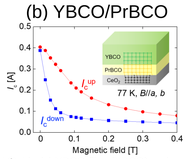


Fig. Magnetic field dependence of I_c^{up} and I_c^{down} in (a) YBCO films(YBCO) and (b) YBCO films grown on a PrBCO buffer layer(YBCO/PrBCO).

$I_c^{up} \fallingdotseq I_c^{down}$

$I_c^{up} > I_c^{down}$

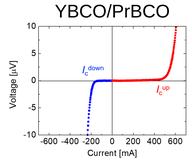


Fig. The typical asymmetric current-voltage characteristics in the YBCO/PrBCO in an in-plane magnetic field of 0.08 T at 77 K.

Asym. = **-103.2** [%]
(77 K, 0.08 T)

PrBCO buffer layer increased the difference between I_c^{up} and I_c^{down}

- Field dependence of *Asym.*

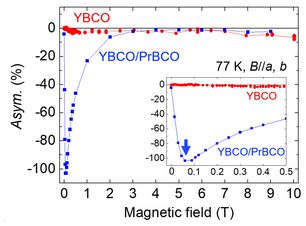


Fig. Magnetic field dependence of I_c asymmetricity *Asym.* in the YBCO and the YBCO/PrBCO in an in-plane magnetic field at 77 K.

Asym.^{MAX} :
the maximum of the *Asym.* for the magnetic field
B^{MAX} :
the magnetic field where *Asym.* is maximum value

- YBCO
  - ✓ *Asym.*^{MAX} = **-3.7** [%]
  - ✓ *Asym.* is almost independent of the magnetic field
- YBCO/PrBCO
  - ✓ *Asym.*^{MAX} = **-103.2** [%]
  - ✓ B^{MAX} = **0.08** [T] (Blue arrow in the left figure)

PrBCO buffer layer enhanced *Asym.*^{MAX}

Effect of PrBCO buffer layer on *Asym.*^{MAX}

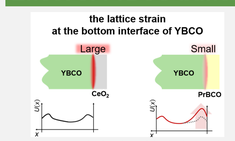


Fig. Schematic drawing of the lattice strain at the bottom interface of YBCO and *U*(*x*).

Surface barrier
C. P. Bean and J. D. Livingston: Phys. Rev. Lett. **12**, 14 (1964).

$$U(x)=\left(\frac{\Phi_0}{4\pi\lambda(x)}\right)^2 \log\left(\frac{\lambda(x)}{\xi}\right)-\left(\frac{\Phi_0}{4\pi\lambda(x)}\right)^2 K_0\left(\frac{2x}{\lambda(x)}\right)+\frac{\Phi_0}{4\pi}H\exp\left(-\frac{x}{\lambda(x)}\right)$$

Strain relaxation → **Small** $\lambda(x)$ → **Large** $U(x)$, $dU(x)/dx$

PrBCO buffer layer enhances rectification due to the strain relaxation

- *T* dependence of *Asym.*^{MAX} and B^{MAX}

35-70 K (**Low-*T***)

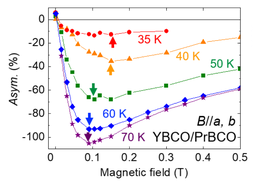


Fig. Magnetic field dependence of I_c asymmetricity *Asym.* in the YBCO/PrBCO in an in-plane magnetic field at 35-70 K.

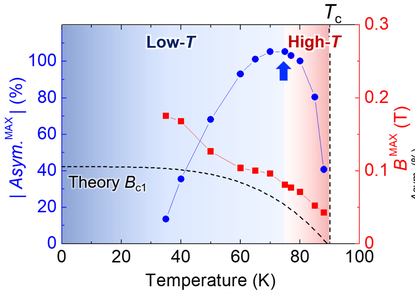


Fig. Temperature dependence of $|Asym.^{MAX}|$ and B^{MAX} in the YBCO/PrBCO.

77-88 K (**High-*T***)

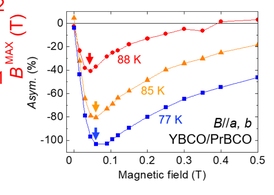


Fig. Magnetic field dependence of I_c asymmetricity *Asym.* in the YBCO/PrBCO in an in-plane magnetic field at 77-88 K.

|*Asym.*^{MAX}| at Low-*T*

Asym.^{MAX} : **-105.3**%(70 K, 0.10 T) ⟶ **-13.6**%(35 K, 0.18 T)

Flux pinning > Surface barrier

- ✓ Oxygen vacancy (Random pin, Weak pinning)
- ✓ Intrinsic pin (*B*//*a*,*b* pin, Weak pinning)

|*Asym.*^{MAX}| at High-*T*

Asym.^{MAX} : **-103.2**%(77 K, 0.08 T) → **-40.7**%(88 K, 0.04 T)

Magnetic penetration depth λ vs Specific length of the film

130 → 400 nm (77 → 88 K)

20-100 nm (Surface roughness) 2-10 nm (Critical thickness)

J. W. Matthews and A. E. Blakeslee: J. Cryst. Growth **27**, 118 (1974).

Discussion about B^{MAX}

B^{MAX} increased monotonically with decreasing temperature

Lower critical magnetic field B_{c1} $\quad B_{c1}=\frac{\Phi_0}{4\pi\lambda(T)^2}\ln\left(\frac{\lambda}{\xi}\right)$

- ✓ $dB^{MAX}/dT \approx dB_{c1}/dT$ (T > 35 K)
  B^{MAX} increased monotonically with decreasing temperature as well as B_{c1}

Magnetic penetration depth λ $\quad \lambda \propto \{1-\left(\frac{T}{T_c}\right)^4\}^{-\frac{1}{2}}$

A. B. Pippard: The Royal Society **216** (1952).

- ✓ $B^{MAX} > B_{c1}$
  B^{MAX} was inconsistent with B_{c1}(Bean-Livingston model)

Experimental methods

- Sample preparation

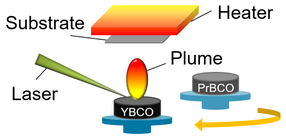


Fig. Schematic drawing of a PLD method

Table Various parameters in film deposition

Parameters	YBCO film	YBCO film grown on a PrBCO buffer layer
Method	Pulse laser deposition(PLD)	
Substrate	CeO_2-buffered IBAD-MgO	
Laser source	KrF-excimer laser	
Laser frequency	100 Hz	
Laser energy density	1.5 J/cm^2	
Temperature	1050 ℃	
O_2 pressure	53 Pa	
Target	$YBa_2Cu_3O_y$ (YBCO)	$PrBa_2Cu_3O_y$ (PrBCO) / $YBa_2Cu_3O_y$ (YBCO)
Films thickness	450 nm	50 nm / 450 nm

- Measurement

Table Various parameters in measurement

Parameters	Conditions
Temperature	35-88 K
Field angle	*B*//*a*, *b*
Magnetic field	0-10 T

10 T cryogen-free superconducting magnet with a He-gas flow cryostat at IMR, Tohoku University

- Definition of asymmetricity

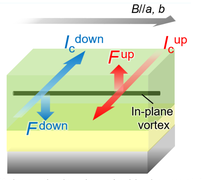


Fig. Schematic drawing of critical current I_c and Lorentz force *F* direction

Vortex motion
- ➢ up
  Bottom → Top
- ➢ down
  Top → Bottom

$$Asym. = \frac{I_c^{down} - I_c^{up}}{(I_c^{down} + I_c^{up}) / 2} \times 100\ [\%]$$

Conclusion

- The optimal operating conditions of the YBCO superconducting diode films was investigated in an in-plane magnetic field of 0-10 T and at 35-88 K.
- Both the *Asym.*^{MAX} and the B^{MAX} were shown to be temperature dependent.
- The *Asym.*^{MAX} showed the maximum value of -105.3% at 0.10 T and at 70 K in the YBCO films grown on the PrBCO buffer layer.

Acknowledgements

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