3E02-03

Photoresponse of $La_{1.85}Sr_{0.15}CuO_4$ nanostrip

H. Shibata[1], N. Kirigane[1], K. Fukao[1], D. Sakai[1], S. Karimoto[2], H. Yamamoto[2]

1. Kitami Institute of Technology, Japan
2. NTT Basic Research Laboratories, Japan

Outline :
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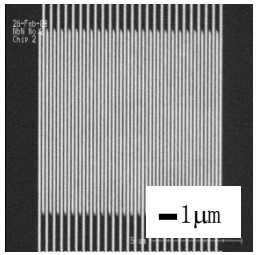
- Fabrication
- Photoresponse
- Summary

Introduction

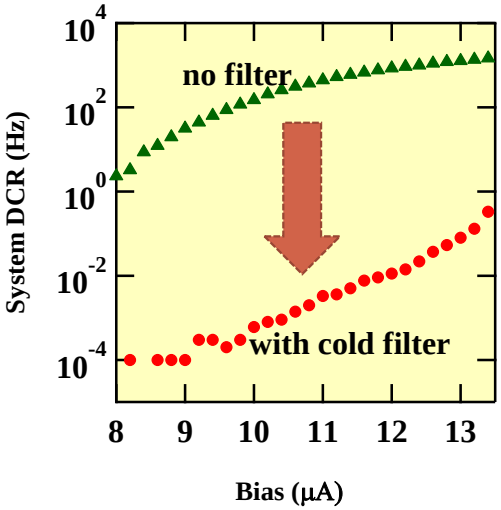


SSPD (SNSPD)

Merits:

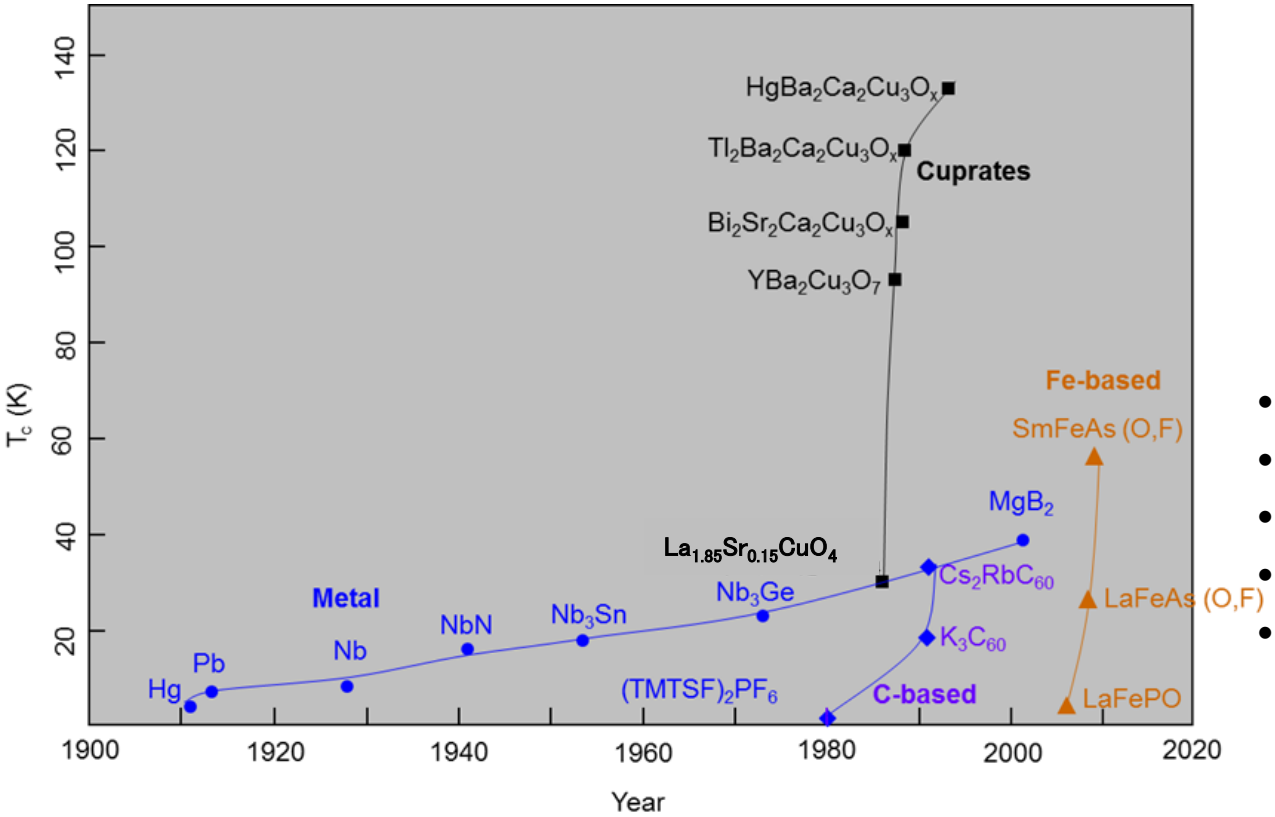
- Detection efficiency close to unity
  - 93%, WSi (Nat. Photon 7, 210 (2013))
  - 92.1%, NbN (arXiv1609.00429)
  - 92%, NbTiN (CLEO2017. FF1E.1)

- Ultralow dark count rate
  - $<10^{-2}$Hz (Appl. Phys. Express 6, 072801 (2013))
  - $<10^{-4}$Hz (Opt. Lett. 40, 342 (2015))



Demerit:

- Low operating temperature
  <3 K for NbN, NbTiN-SSPD
  <1 K for WSi-SSPD



SSPD using high T_c materials is required

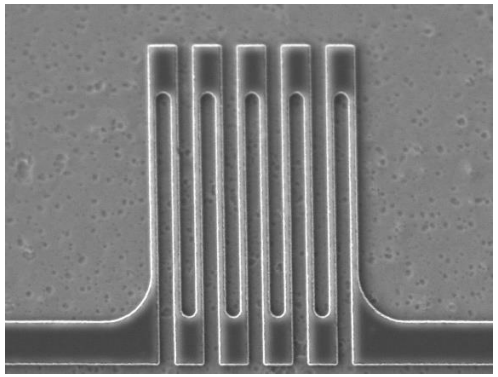
- A15 (T_c~20K)
- MgB_2 (T_c~39K)
- fullerene-based (T_c~30K)
- Fe-based (T_c~50K)
- Cuprates (T_c~130K)

…

MgB_2-SSPD

- Single photon detection

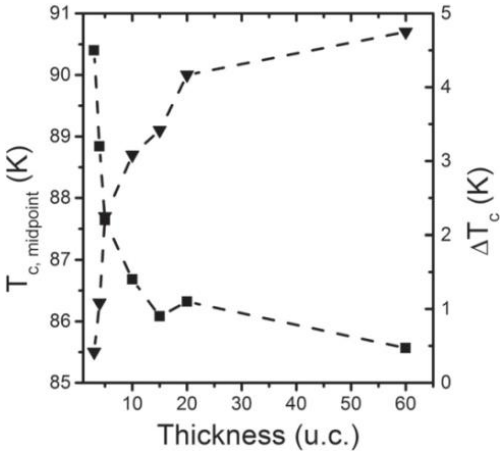
  at 10 K (Appl. Phys. Express 7, 103101(2014))
  at 11 K (CLEO2017, FF1E.7)



$YBa_2Cu_3O_{7-x}$-SSPD

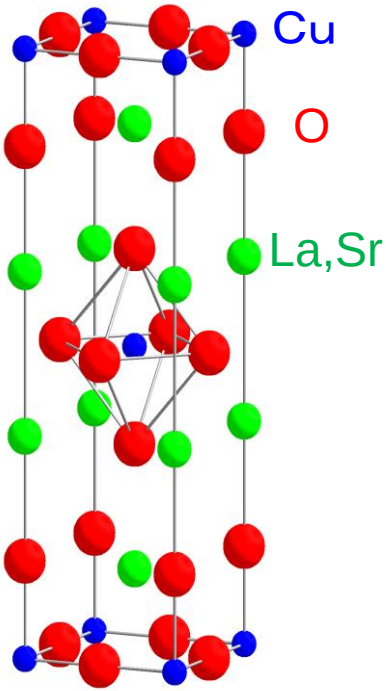
- Optical response is observed, but not single-photon detection (SUST 27, 044027 (2014))

- T_c strongly decreases as the thickness decreases (SUST 29, 065017 (2016))

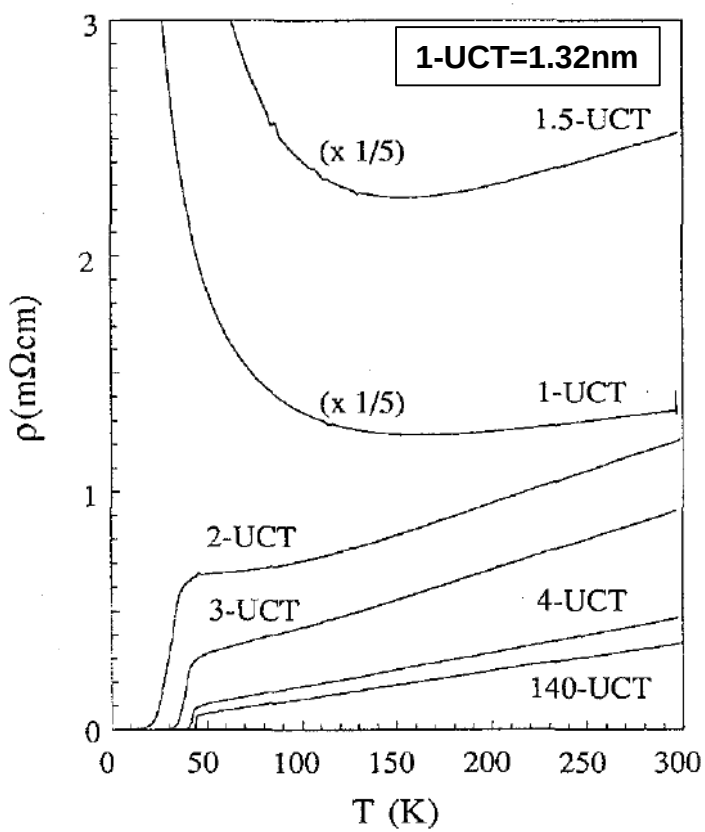


1 u.c. = 1.17nm

$La_{1.85}Sr_{0.15}CuO_4$ (LSCO)



$La_{1.85}Sr_{0.15}CuO_4$
(T_c = 37K)



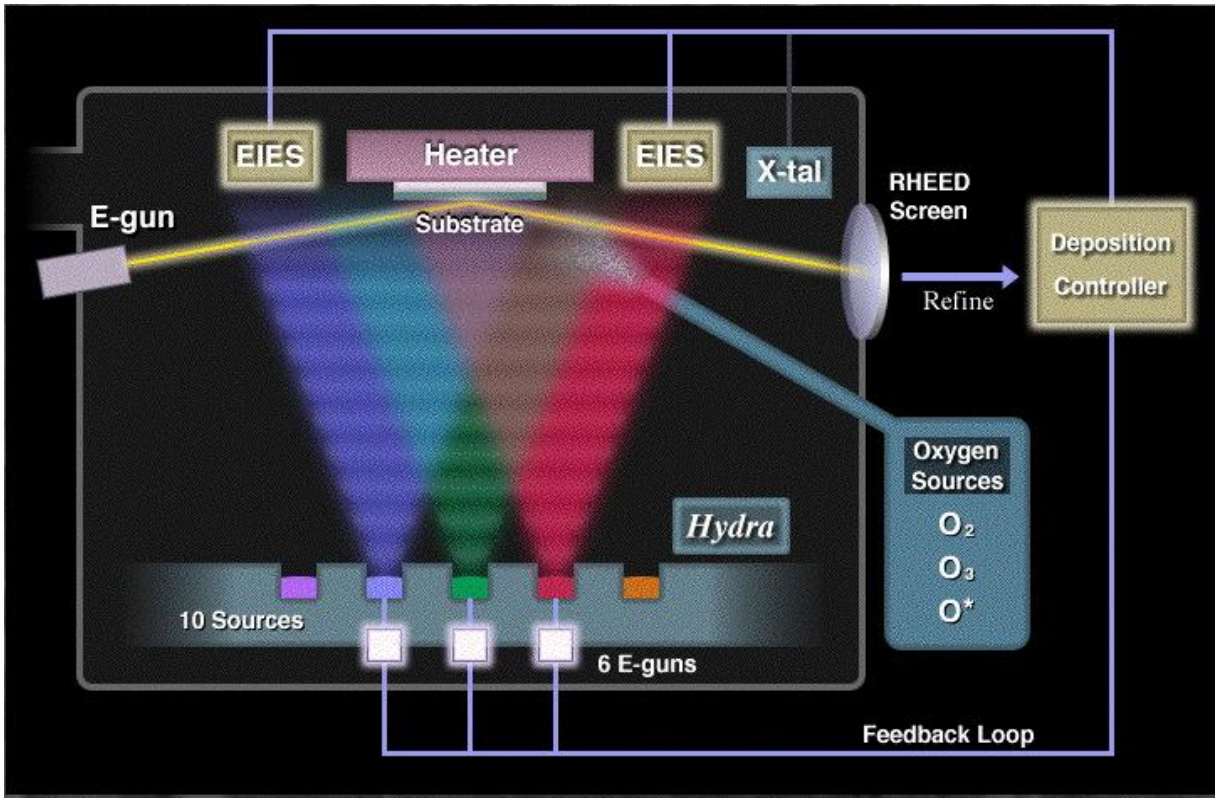
Physica C274, 227 (1997)

High qualily ultrathin film is available for $La_{1.85}Sr_{0.15}CuO_4$

$La_{1.85}Sr_{0.15}CuO_4$-SSPD

Fabrication

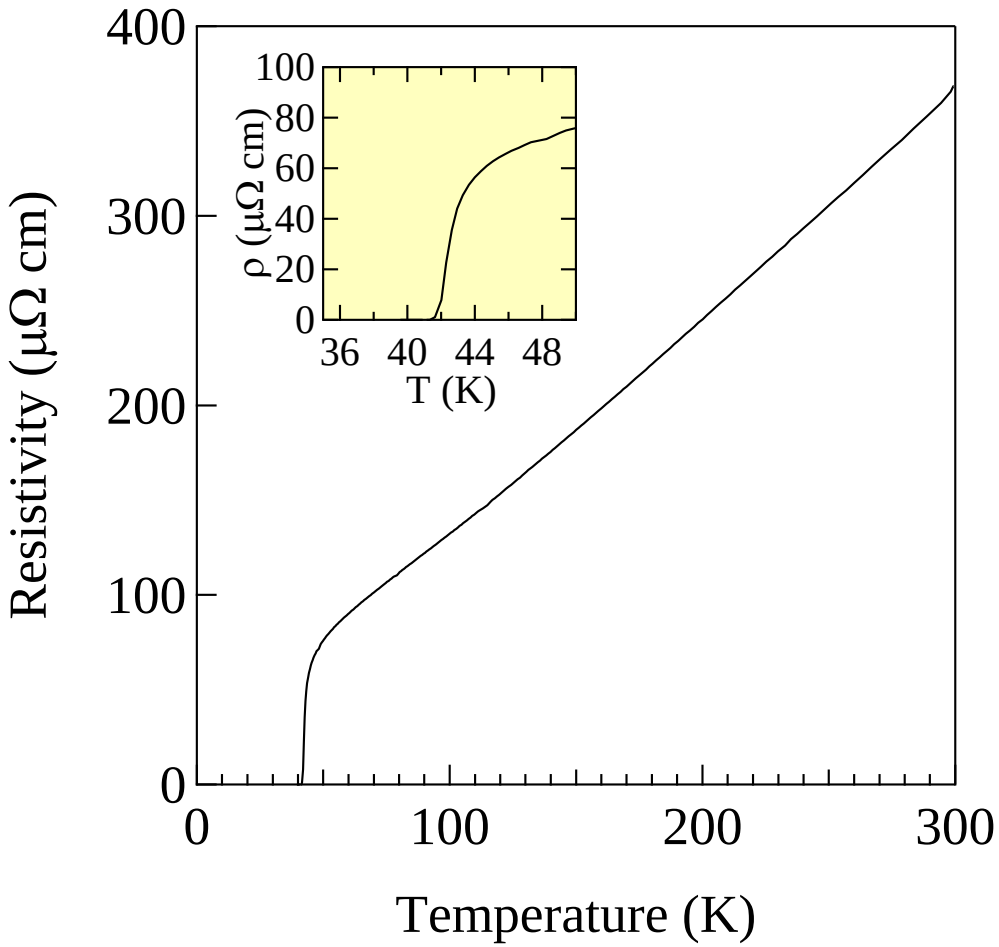
Ultrathin film growth of $La_{1.85}Sr_{0.15}CuO_4$



MBE apparatus

- E-beam deposition of metal sources
- Oxidation using radical oxygen (O*)
- Precise deposition rate control using EIES
- In-situ RHEED monitor
- $LaSrAlO_4$ substrate
- T_s = 670˚C

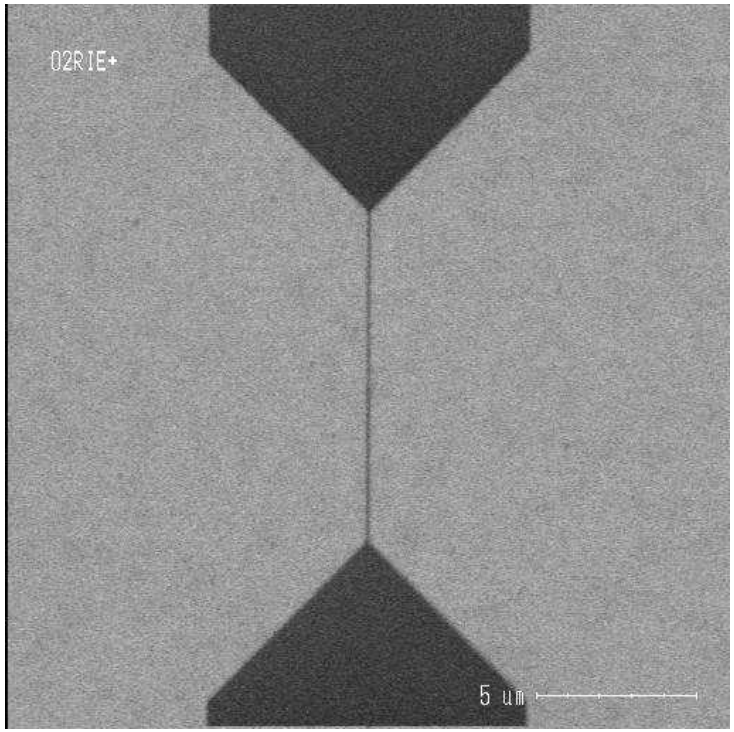
Resisitivity

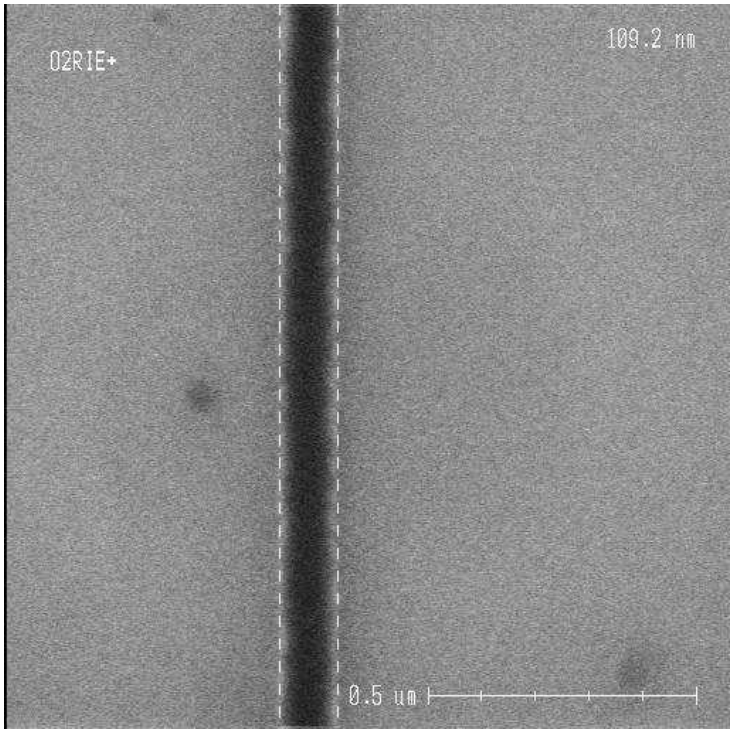


- T_c = 41.6 K for 5 nm-thick $La_{1.85}Sr_{0.15}CuO_4$ film on $LaSrAlO_4$ substrate
- T_c increases by the compressive strain effect

$LaSrAlO_4$	3.762 Å
$La_{1.85}Sr_{0.15}CuO_4$	3.777

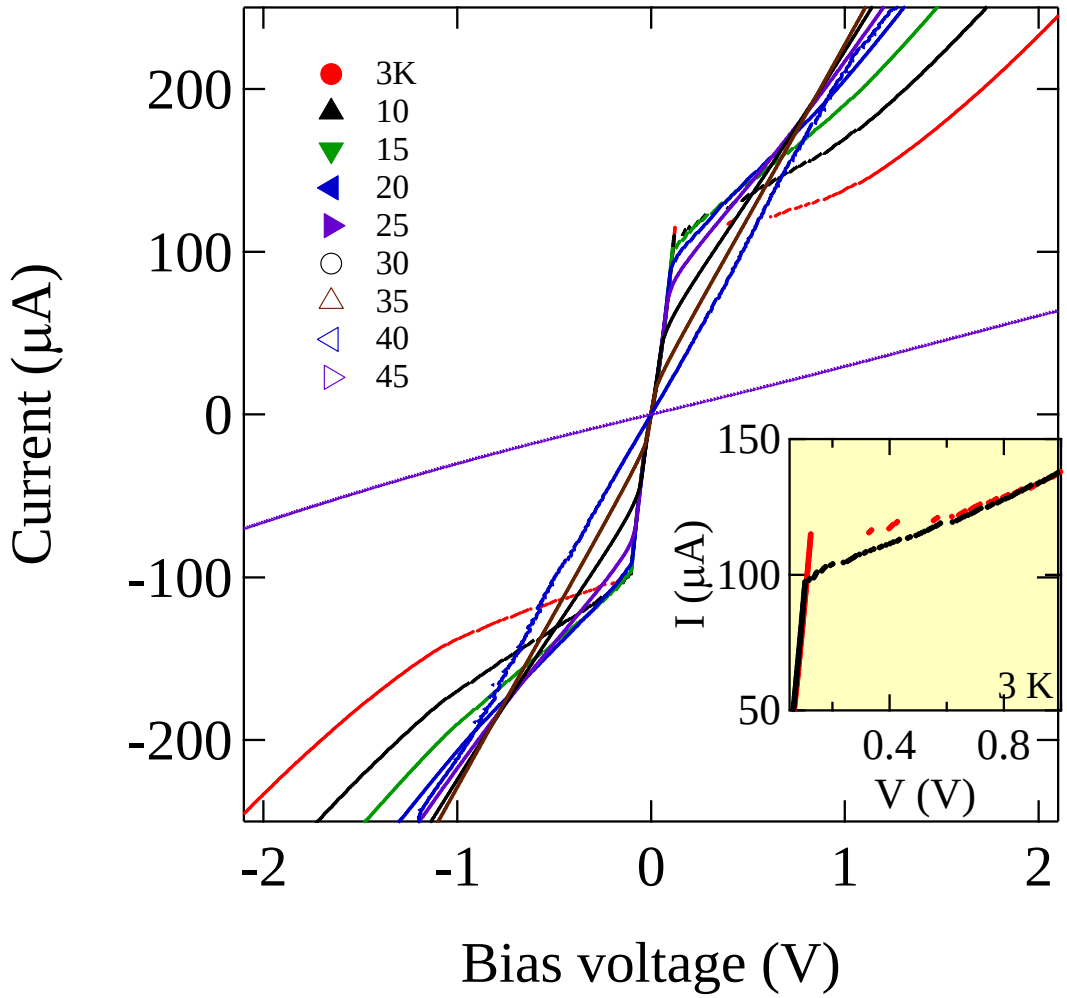
SEM image (before milling)





- 10 μm × 100 nm × 5 nm single nanostrip by Ar ion milling
- AlN passivation

Current-Voltage (I-V) Characteristics

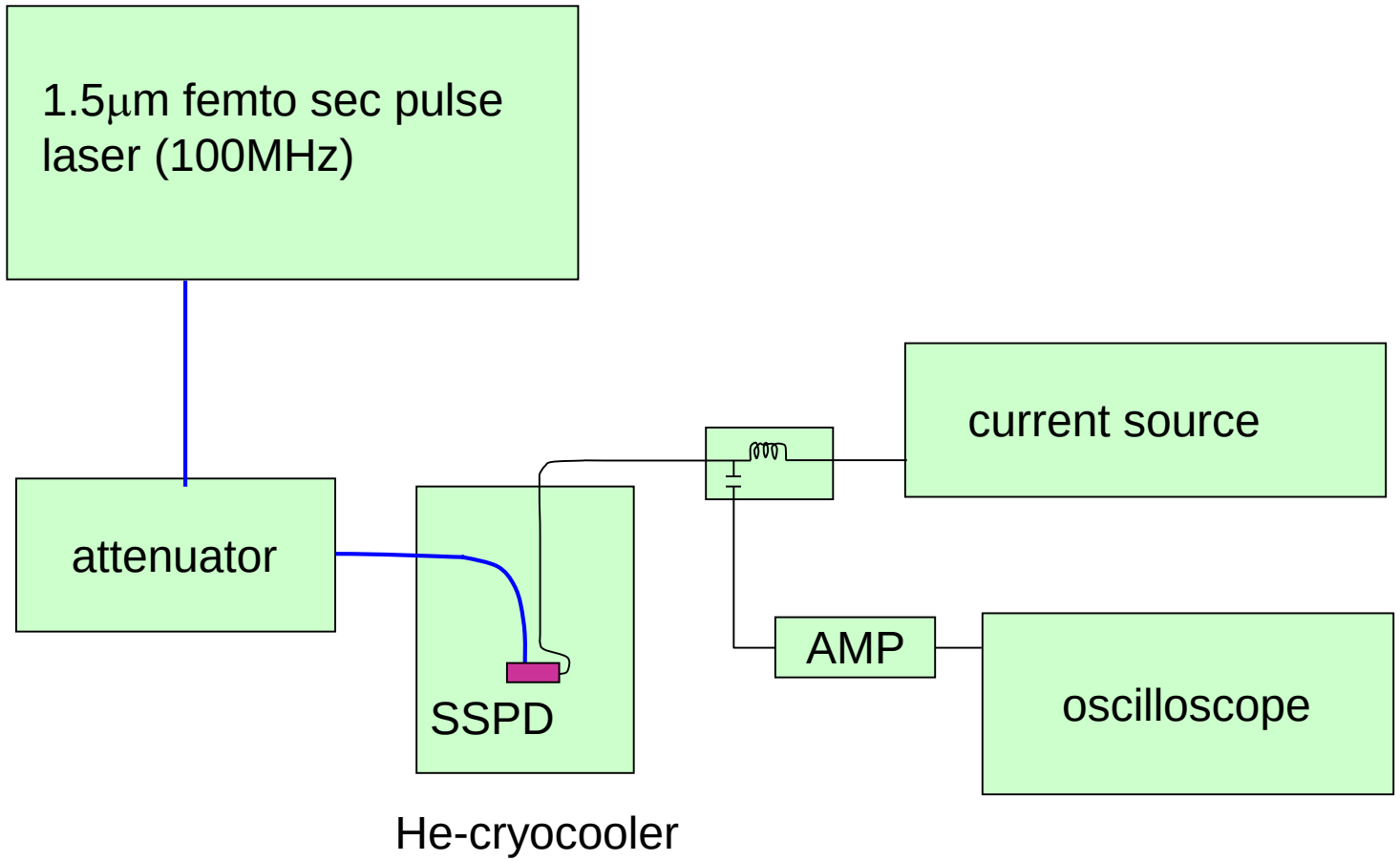


- A clear voltage jump at I_c
- Hysteresis behavior
- I_c (3 K) = 115 μA
- $J_c = 2.3 \times 10^7$ A/cm^2
- Slope decreases at 45K

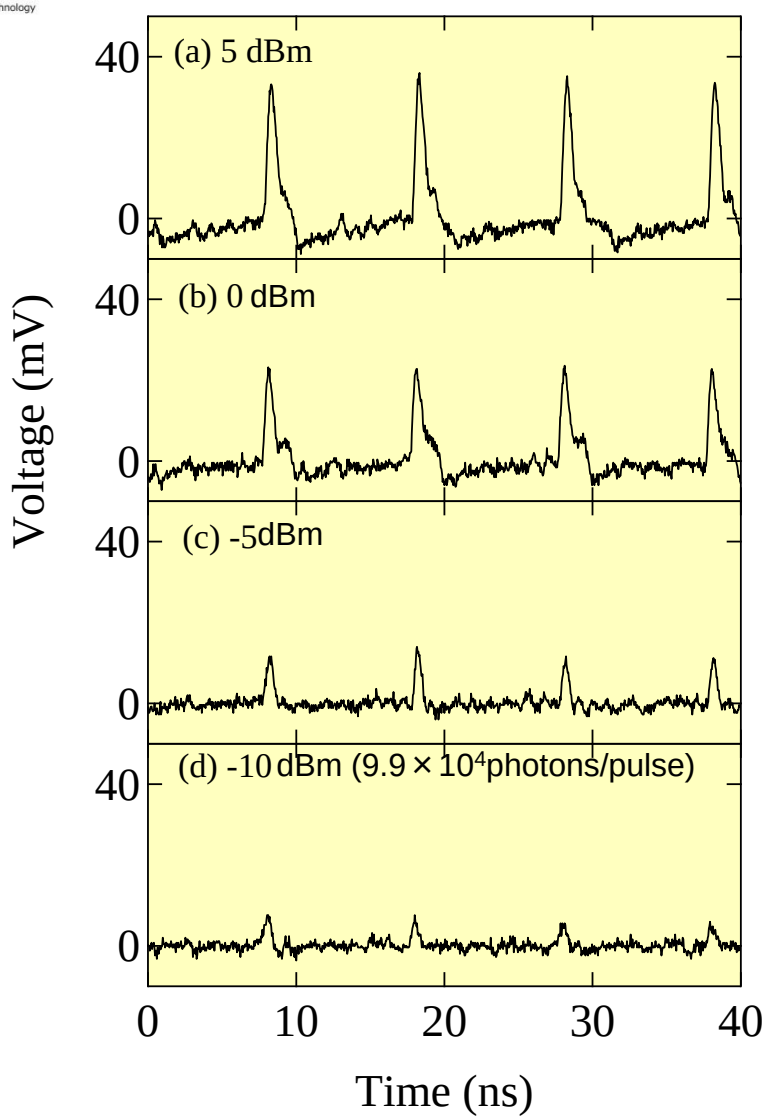
$J_{depair} = 7.6 \times 10^7$ A/cm^2
(ξ_{ab}=3.2nm, λ_{ab}=204nm)

Photoresponse

Optical Setup

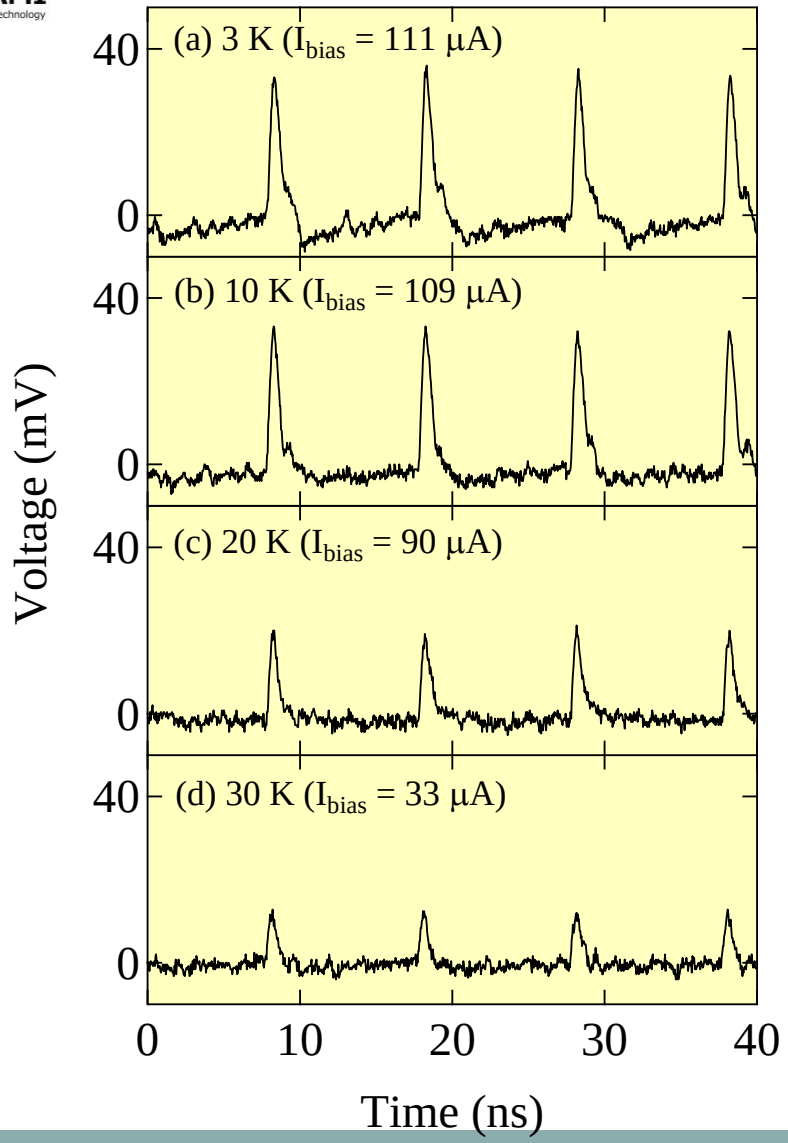


Optical intensity dependence



- Clear photoresponse at high bias current (I_{bias} = 111μA)
- Pulse height decreases as the optical intensity decreases
- Pulse disappears below -10 dBm

Temperature dependence



- The pulse height decreases as the temperature increases
- The pulse can be observed up to 30 K

Discussion

- Possibility of single-photon detection using $La_{1.85}Sr_{0.15}CuO_4$

Comparison with MgB_2-SSPD

- 300nm-wide MgB_2

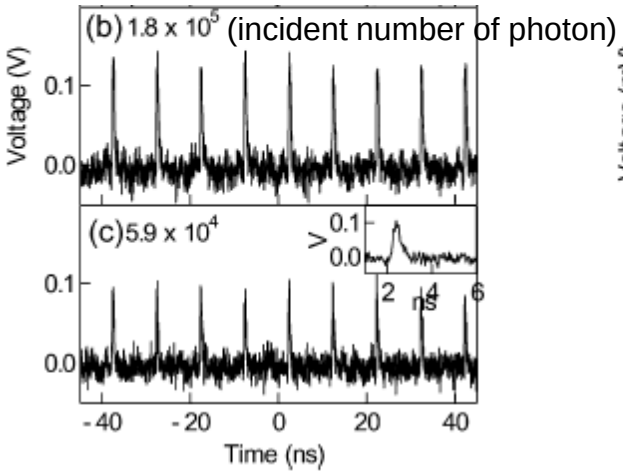
  Bolometric response

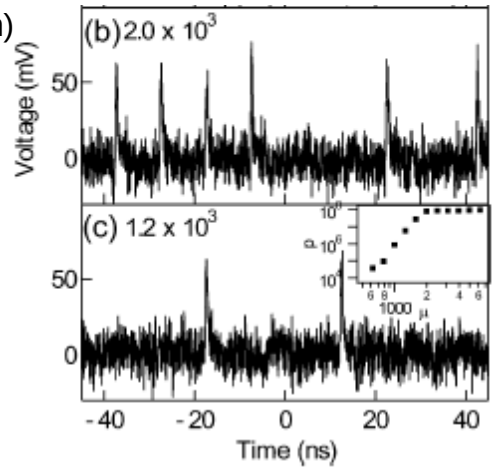
- 200nm-wide MgB_2

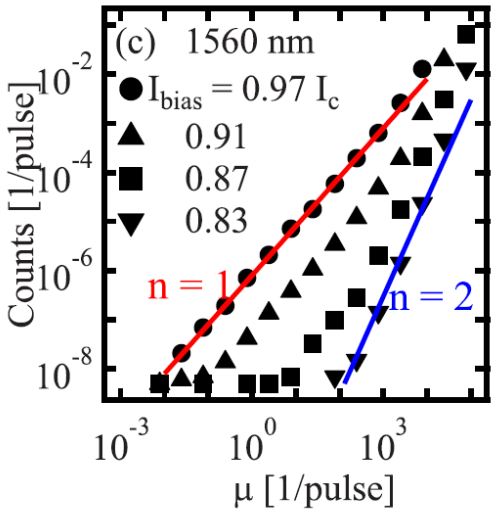
  Multi-photon detection regime

- 100nm-wide MgB_2

  Single-photon detection regime







IEEE Trans. Appl. Supercond. 19, 358 (2009), Appl. Phys. Lett. 97, 212504 (2010)

Large I_c value

I_c=115μA is about 5 times larger than the standard SSPD (I_c=20μA).

- Nanostrip with 20nm-wide × 5nm-thick is required of single-photon detection using $La_{1.85}Sr_{0.15}CuO_4$

- The present $La_{1.85}Sr_{0.15}CuO_4$-SSPD may be useful for detecting high-energy particle (electron, x-ray, neutron, biomolecular ion, etc)

Summary

- High quality $La_{1.85}Sr_{0.15}CuO_4$ nanostrip with 100nm-wide × 10 μm-long × 5 nm-thick
  - ✓ Clear I-V characteristics (voltage jump, hysteresis, ~J_{depair})
  - ✓ Photoresponse up to 30K
  - ✓ Needs to reduce the width of the nanostrip for single-photon detection

Supecond. Sci. Technol. **30**, 074001 (2017)