Photoresponse of $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$ nanostrip

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Outline:
- Introduction
- Fabrication
- Photoresponse
- Summary
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$_2$Cu$_3$O$_{7-x}$-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. = 1.17 nm
La$_{1.85}$Sr$_{0.15}$CuO$_4$ (LSCO)

High quality ultrathin film is available for La$_{1.85}$Sr$_{0.15}$CuO$_4$

Ultrathin film growth of La$_{1.85}$Sr$_{0.15}$CuO$_4$

- E-beam deposition of metal sources
- Oxidation using radical oxygen (O$^*$)
- Precise deposition rate control using EIES
- In-situ RHEED monitor
- LaSrAlO$_4$ substrate
- $T_s = 670^\circ$C
- $T_c = 41.6$ K for 5 nm-thick $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$ film on $\text{LaSrAlO}_4$ substrate

- $T_c$ increases by the compressive strain effect

<table>
<thead>
<tr>
<th>Composition</th>
<th>$\text{d} = \text{Å}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{LaSrAlO}_4$</td>
<td>3.762</td>
</tr>
<tr>
<td>$\text{La}<em>{1.85}\text{Sr}</em>{0.15}\text{CuO}_4$</td>
<td>3.777</td>
</tr>
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</table>
SEM image (before milling)

- 10 µm × 100 nm × 5 nm single nanostrip by Ar ion milling
- AlN passivation
- A clear voltage jump at $I_c$
- Hysteresis behavior
- $I_c (3 \text{ K}) = 115 \ \mu\text{A}$
- $J_c = 2.3 \times 10^7 \ \text{A/cm}^2$
- Slope decreases at 45K

$$J_{\text{depair}} = 7.6 \times 10^7 \ \text{A/cm}^2$$

($\xi_{ab}=3.2\text{nm}, \lambda_{ab}=204\text{nm}$)
Photoresponse

Optical Setup

1.5\(\mu\)m femto sec pulse laser (100MHz)

attenuator

SSPD

He-cryocooler

current source

AMP

oscilloscope
Optical intensity dependence

- Clear photoresponse at high bias current ($I_{bias} = 111 \mu A$)
- 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.

(a) 3 K (I_{bias} = 111 \, \mu A)
(b) 10 K (I_{bias} = 109 \, \mu A)
(c) 20 K (I_{bias} = 90 \, \mu A)
(d) 30 K (I_{bias} = 33 \, \mu A)
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

**Large $I_c$ value**

$I_c=115\mu A$ is about 5 times larger than the standard SSPD ($I_c=20\mu A$).

- Nanostrip with 20nm-wide $\times$ 5nm-thick is required for 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, $\sim J_{\text{depair}}$)
- Photoresponse up to 30K
- Needs to reduce the width of the nanostrip for single-photon detection
