Aluminum thickness dependence of spatial profile in niobium-based superconducting tunnel junction

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Development of advanced X-ray STJ detectors

Bias-dependence
E-dependence
Size-dependence
H-dependence
AI-dependence
Optimization of STJ detectors
Development of advanced X-ray detectors

Goal

Energy resolution - < 20 eV for 6 keV x-ray
Counting rate - > 100K cps
Detection area - ~ 1mm²
Absorption rate - > 70% for 6 keV x-ray
Full illumination with $^{55}$Fe X-ray source (5.9keV, 6.4keV)

200µm

Nb(200)  Al(30)  Al(30)  Nb(200)

Bias: 0.7mV, 300nA

(a)

Bias: 0.3mV, 16nA

fd21-06-16nA

92eV

71eV

(b)

The answer is spatial nonuniformity.
PF@KEK, TERAS@AIST

800 MeV electron storage ring, "TERAS"

- 300 – 800 MeV
- 300 mA

- TERAS
- BL1 1
- BL2 1, 2
- Beam position monitors
- Superconducting split coil

- Cryostat
- LN₂
- LIHe
- 3He

- X-ray beam
- Pinhole
- Be-window

Data acquisition system

MCA

Position controller

KEK PF
Harald Pressler
Bias-dependence (Al30nm)

STJ : fd21 200µm-square junction

Bias current: Low
Line shape: concave

Bias current: High
Line shape: convex
H-depence

$V_{\text{bias}} = 0.6 \text{mV} = \Delta/e$  
$V_{\text{bias}} = 0.3 \text{mV}$

1D scan

Risetime

Risetime

H: High

Large output area suppressed
E-dependence of 1D scan

$E_x \geq \sim 1\text{keV}$

No obvious dependence
QP diffusion model

Inadequate for explaining characteristics (bias dependence, etc)

AI thickness dependence?
1. Using **lift-off technique**, tri-layers were patterned on the wafer. The tri-layer, Nb(100-200)/Al-AlOx(50-100)/Al(50-100)/Nb(100-200) in nm, was deposited by **DC-sputtering**. The surface of the Al layer was oxidized for 1 hour in O2 atmosphere of 9 torr at room temperature. [1)+2) show]

2. To form the top electrodes, top Nb and Al layers were removed by **RIE** and **Ar ion milling**, respectively. [3) shows]

3. A SiO2(800-1200nm) isolation layer was deposited by **RF-sputtering** and patterned by the **lift-off technique**. [4)+5) show]

4. A Nb film with a thickness between 1000 and 1400 nm was deposited by **DC-sputtering**. Electric leads and contact pads were formed by the **lift-off technique**. [6) shows]
KEK-PF BL 13B2

- Energy range: 4-29keV
- Photon Flux: \( \sim 1 \times 10^{12}/s \cdot \text{mm}^2 \)
- (11keV, 300mA)
- Energy resolution: \( E/\Delta E = \sim 5000 \)
- Light source: Type: Linear Multipole Wiggler MPW #13-W
  - (\( \lambda u: 18\text{cm}, N_{\text{period}}: 27, Ec: 6.24\text{keV} \))
- Optics: Double-Crystal Monochrometer [Si(111)]
  - with Sagittal Focusing optics
Al-dependence of 1D scan

E=6keV

$V_{\text{bias}} = \Delta/e$

charge output

Al(30nm)    Al(50nm)    Al(70nm)

Complex dome    Simple dome
E-linearity

Position: junction center

Al thickness
Thin

$E$-non-linearity pronounced

$H = c_1 E - c_2 E^2$

center of 200 $\mu$m-square STJ

- 30 nm
- 50 nm
- 70 nm
Bias-dependence (Al50nm)

E_x: 6keV

No obvious dependence
Explanation of Al-thickness dependence

- X-ray
- Nb
- Thin Al
- QPs
- Tunnel barrier
- Thick Al
- Al

QP density: High (Thin Al) vs. Low (Thick Al)

$P_{\text{Recombination}}$: High (Thin Al) vs. Low (Thick Al)

QP loss: Large (Thin Al) vs. Small (Thick Al)
Conclusion

1. We fabricated the Nb-STJs having the Al layers of different thicknesses by the lift-off technique.
2. The Al thickness dependence of the spatial profile was measured by LTSSM.
3. The spatial uniformity is improved by increasing the Al thickness.
4. The Nb-based STJ is not appropriate for the direct detection of high-energy X-rays above about 1keV.