

# Superconducting Quantum Devices from Mesoscopic Physics to Metrology Applications

## 超伝導量子デバイスによるメソスコピック物理と標準応用の研究

水柿義直, 守屋雅隆, 小林忠行, 島田宏

電気通信大学

〒182-8585 東京都調布市調布ヶ丘1-5-1

Y. Mizugaki, M. Moriya, T. Kobayashi, and H. Shimada

The University of Electro-Communications

1-5-1 Chofugaoka, Chofu, Tokyo, 182-8585

(mizugaki@ee.uec.ac.jp)

マクロな量子現象である超伝導やジョセフソン効果を利用することで、高精度・高感度な電子デバイスが実現可能となる。我々は、新規電子デバイス実現を目指して次のような研究を行っている。

- 微小トンネル接合における帯電効果、スピン蓄積効果の解明とそのデバイス応用
- 高温超伝導体の波動関数対称性の解明とそのデバイス応用
- 超伝導量子干渉素子のマイクロ波応答特性とその応用
- SFQ電圧増倍回路用デバイスの高機能化

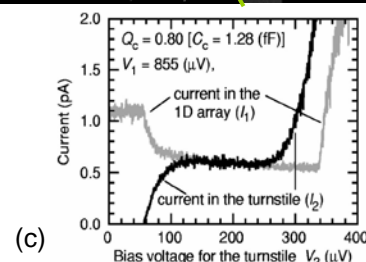
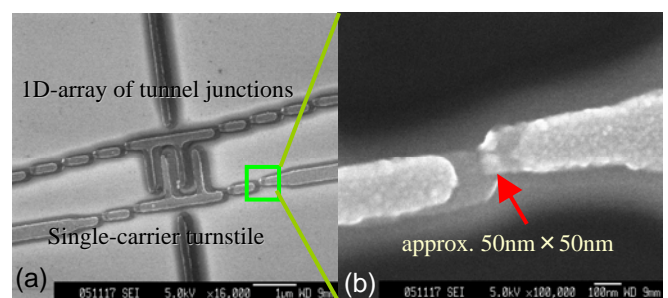
Superconductivity and the Josephson effects are attractive to realize ultra-accurate and ultra-sensitive electron devices because of their macroscopic quantum properties. We have been developing novel superconducting devices, including the following topics:

- Novel devices based on charging effects and spin accumulation in mesoscopic systems.
- Investigation of asymmetric wave-function in high-Tc superconductors and its application.
- RF responses of superconducting quantum interference devices (SQUIDs).
- Design of advanced devices for a SFQ voltage multiplier.

## 微小トンネル接合による電流ミラー回路 Current Mirror Composed of Mesoscopic Tunnel Junctions

微小トンネル接合において発現するクーロン閉塞を利用することで、電荷キャリア（電子や超伝導電子対）を1個の単位で操作できる電子デバイス（単一キャリア素子）が実現できる。我々は、このような単一キャリア素子を利用した電流ミラー回路の設計・試作および動作検証を行っている。この電流ミラー回路では、その精度を単一キャリアの電荷レベルで制御できることから、将来の電流標準システムへの応用が期待される。

We have been developing quantum current mirrors based the Coulomb blockade phenomena in mesoscopic tunnel junctions. Arrays of tiny junctions are the cores of the quantum current mirrors, where a single-carrier (single electron or single Cooper-pair) is transferred one by one. Current mirrors having the accuracy of single-carrier charge would be applicable to future current-standard systems.

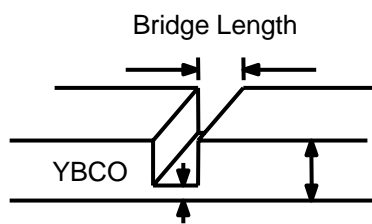


Quantum current mirror based on a turnstile device. (a) SEM image. (b) Magnified image for a single junction. (c) Monte Carlo simulation result for the normal-conducting state.

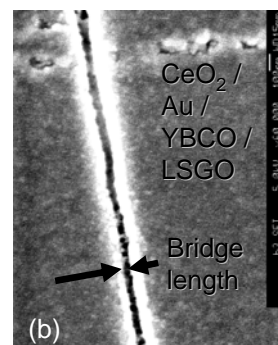
## 膜厚変化形ブリッジを利用した高温超伝導体波動関数対称性の研究 Variable Thickness Bridges to Investigate Asymmetric HTS Wave-Function

我々は人工的な界面を持たない膜厚変化形ブリッジ (variable thickness bridge: VTB) を利用して、高温超伝導体における波動関数対称性の調査およびそのデバイス応用を試みている。これまでa軸配向YBCO薄膜の微細加工において、ブリッジ長20nmの素子の作製に成功している。

We have been investigating asymmetric HTS wave-function by using variable thickness bridge (VTB) structures. A-axis oriented YBCO thin films on a LSGO substrate are employed for a HTS material. We have succeeded so far to fabricate a VTB with the bridge length as short as 20 nm.



(a)



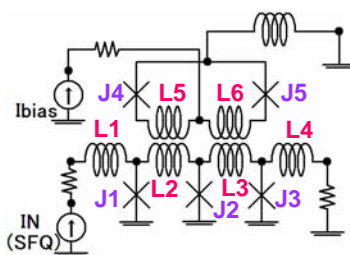
(b)

Variable thickness bridge (VTB). (a) Schematic drawing of a VTB. (b) SEM image of an a-axis oriented YBCO VTB on a LSGO substrate. Bridge length is approximately 20 nm.

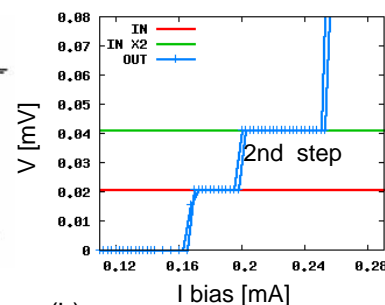
## 高精度SFQ電圧2倍器 Precise Voltage Doubler Based on SFQ Devices

電圧を高精度にコピーするSFQ-to-SFQコンバータを多段接続することで、高精度な電圧増倍回路が実現されている。我々は、従来のSFQ-to-SFQコンバータの素子パラメータを見直し、SFQ-to-DFQ (Double Flux Quanta) コンバータ動作、すなわち入力電圧を2倍にする動作が可能であることを数値計算で確認した。現在、回路の試作と評価を行っている。(産業技術総合研究所との共同研究)

An SFQ-to-SFQ converter precisely copying an input voltage is a basic component of an SFQ voltage multiplier. We have proposed a SFQ-to-DFQ converter (voltage doubler), which doubles the input voltage. Our first design of the SFQ voltage doubler will be tested soon. (Collaboration with AIST.)



(a)



(b)

SFQ voltage doubler. (a) Schematic configuration. The input voltage appearing across the JTL (J1, J2, J3) is doubled at the output voltage across the SQUID (J4, J5). (b) Numerical result of an SFQ voltage doubler utilizing the 2nd step.

## Publications

- (1) Y. Mizugaki, "Numerical investigation on the current mirror effect in a single-electron turnstile capacitively coupled to a one-dimensional array of small junctions," *J. Appl. Phys.* **94** (2003) pp.4480-4484.
- (2) Y. Mizugaki, "Numerical investigation for the frequency dependence of Shapiro steps in an RF-field-driven SQUID," *Supercond. Sci. Tech.* **16** (2003) pp.1380-1382.
- (3) Y. Mizugaki, Y. Uematsu, S. -J. Kim, J. Chen, K. Nakajima, T. Yamashita, H. Sato, and M. Naito, "Intrinsic Josephson junctions in c-axis oriented  $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$  thin films," *J. Appl. Phys.* **94** (2003) pp.2534-2537.
- (4) 水柿義直, "3接合SQUIDの単一磁束量子ポンプ動作と単一電子デバイスとの双対性," *応用物理* **73** (2004) pp.41-44.
- (5) Y. Mizugaki and J. Chen, "Model Analysis for a Current-Step-like Structure in a High-Tc Josephson Device Coupled to a Microwave Signal," *J. Appl. Phys.* **97** (2005) pp.063906-1-5.
- (6) Y. Mizugaki and H. Shimada, "Monte Carlo Study on the Charge Transport in Slantingly Coupled Arrays of Small Tunnel Junctions," *Phys. Rev. B.* **71** (2005) pp.115103-1-7.
- (7) Y. Mizugaki, H. Hakii, M. Moriya, K. Usami, and T. Kobayashi, "Mutual Inductance Coupled through Superconducting Thin Film in Niobium Josephson Integrated Circuits," *Jpn. J. Appl. Phys. Part 2*, **44** (2005) pp.L763-L765.
- (8) Y. Mizugaki, H. Hakii, M. Moriya, K. Usami, and T. Kobayashi, "Numerical and experimental evaluation of mutual inductances between two superconducting striplines coupled through a superconducting intermediate layer," *IEICE Electronics Express* **3** (2006) pp.64-69.