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Operation of a Single Flux Quantum 4-stage Shift Register Fabricated with High T_c Ramp-edge Junction Technology

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고온 초전도 경사형 모서리 접합을 이용한 4단 쉬프트 레지스터의 동작

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Abstract

We have fabricated a single flux quantum 4-stage shift register with interface-controlled $Y_1Ba_2Cu_3O_{7-x}$(YBCO) Josephson junction. The YBCO Josephson junctions showed RSJ-like current-voltage(I-V) curves at temperatures 45~80K. We tested load and shift operation of shift register with binary data sequences "1000", "1010", "1011", and "1111" at 58K. For all the binary data sequences, the shift register operated successfully. By operating the circuit with proper current pulses, we observed no errors during at least 12 hours operation for all the data sequences.

Keywords : Single flux quantum, shift register, interface engineered Josephson junction

I. Introduction

Rapid single flux quantum(RSFQ) digital devices have been investigated extensively due to their high speed and low power consumption[1]. Devices based on low T_c niobium trilayer technology are so advanced that they are now on the edge of practical component applications[2]-[3].

On the other hand, high T_c RSFQ circuits are still quite simple because of immature fabrication technology, which is mainly resulted from complex structure of high T_c superconductor. However, development of high T_c RSFQ is desirable because they are expected to have higher operation speed and higher operation temperature.

Among the high T_c RSFQ circuits, shift register is important component in RSFQ circuits such as memory system, synchronizers, and packet switch[4]-[5]. Until now, a few high T_c RSFQ shift registers are reported. However, they are fabricated on bicrystal substrate[6]-[7].

We have fabricated and tested a high T_c RSFQ 4-stage shift register with interface-controlled ramp-

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edge Josephson junction. By monitoring read SQUIDs at first and last stage of shift register we sensed all the individual data states during the operation of shifter register.

II. Experiments

A. Fabrication

We fabricated interface-controlled Josephson junction on $SrTiO_3$(STO) (100) single crystal. First, we deposited 200nm thick YBCO bottom electrode and 300nm Sr_2AlTaO_6 insulating layer on STO single crystal using pulsed laser deposition(PLD), successively. Bottom YBCO electrode was patterned by photolithography and ramp-edge junction surface was modified by Ar ion milling. After ion milling, the ion-bombarded surface was annealed for 30min. under oxygen atmosphere. Subsequently, 200nm thick top YBCO electrode was deposited. Detailed fabrication process is described elsewhere[8]. Then, we patterned top electrode by photolithography. Fig. 1 is optical micrograph of our 4-stage shift register.

B. Measurement

The fabricated shift register was tested in liquid helium dewar with a single magnetic shield. The temperature of the device was controlled within ± 0.01K. Keithley 220/224 current sources were used for supplying all the bias currents. The current pulses that were injected into the shift register bias lines were supplied by a set of D/A converters, HP E1328A. Keithley 181 nanovoltmeter and 2001 multimeter were used to measure the output voltages from the read SQUIDs. All the electrical lines connected to the device were filtered with low pass RC filters with the cutoff frequency at 10 Hz to minimize the external noise.

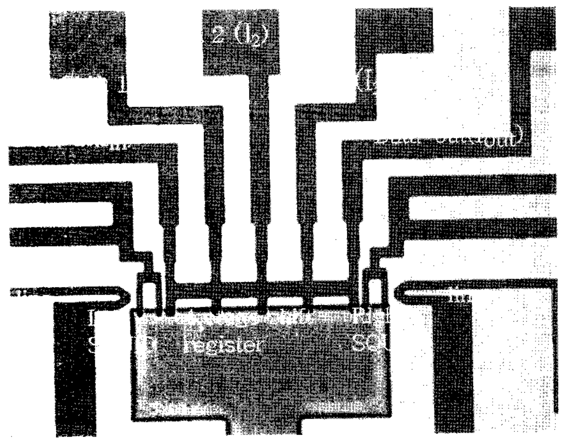

Fig. 1. Optical micrograph of 4-stage shift register that was fabricated with interface-controlled YBCO Josephson junction.

III. Results and discussion

We measured current-voltage(I-V) characteristics of Josephson junctions in read SQUID, which are shown in Fig. 2. Over the temperature range of 45-80K, RSJ-like I-V curves were observed.

We checked V-Φ modulation of left and right read SQUID to set the read SQUIDs at optimum condition. Fig. 3 shows V-Φ modulation for both read SQUIDs, which were measured simultaneously. With the voltage modulation periods, mutual inductance between the two read SQUIDs and the control lines were calculated[6]. The mutual inductance for the left SQUID is 0.8pH and that for the right SQUID is 1.2pH, respectively. During the operation of shift register, the read SQUIDs were set at points where the transfer coefficients ,V_Φ ($V_\Phi \equiv |\partial V/\partial \Phi|$), were maximum. All operation should be checked at temperature where thermal noise can not be effective, and 58K was one of those temperatures and one of higher temperature points for high temperature superconducting electronics.

We loaded data sequences of "1000", "1010", "1011", and "1111" to the shift register circuit to

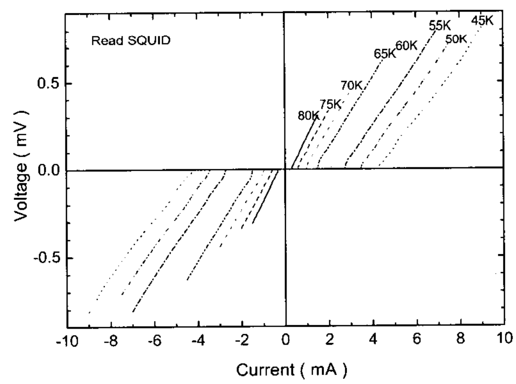

Fig. 2. RSJ-like I-V curves of Josephson junction at various temperatures.

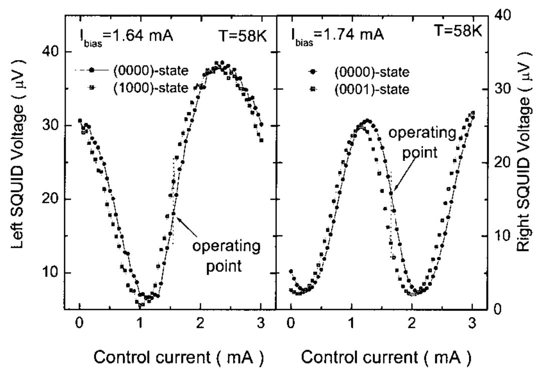

Fig. 3. V-ϕ modulation curve of the two read SQUIDs.

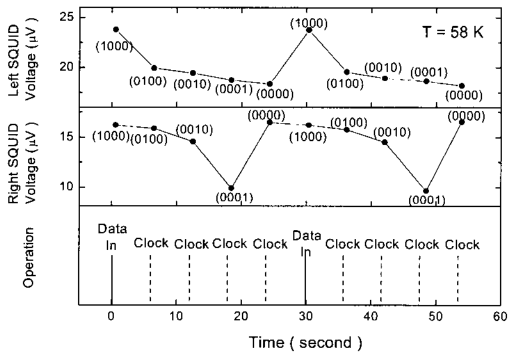

Fig. 4. Voltage responses of the two read SQUIDs during the operation of the shift register for the binary data sequence "1000". The top section shows the output voltage from the read SQUID on the left side of the shift register, and the middle section shows the output voltage from the right register.

check the proper shift register operation.

When the data "1000" was loaded into the first stage(leftmost) by the "Data-in(I_{in})" pulse, the left SQUID voltage changed to the high level via the change of one flux quantum in the first stage. As successive clock pulses were applied, the stored flux was moved to the second, third, and final stage. Along the flux movement, the voltage level of left SQUID decreased and eventually arrived at initial level just after the fourth clock was applied. On the other hand, the voltage level of right SQUID decreased and it reached minimum level when the flux was in the final state.

We tested for the binary data sequence "1010".

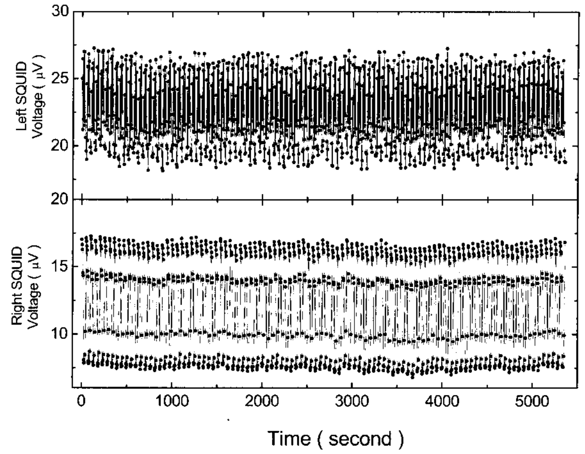

Fig. 5. Repeated load and shift operation of the shift register for the binary data sequence "1010".

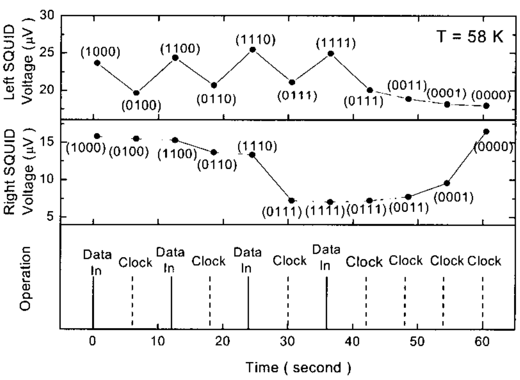

Fig. 6. Voltage responses of the two read SQUIDs during the operation of the shift register for the binary data sequence "1111".

By using proper combination of "Data-in" and "Clock" operations, we loaded data sequence "1010" into the circuit. The load and shift operation were repeated for more than 1.5hours, which corresponds to more than 100 cycles. Fig. 5 is the results of the load and shift operation for the binary data sequence "1010".

We also checked the operation for "1011" and "1111", which have successive "1". Fig. 6 is the result of load and shift operation of the shift register for the binary data sequence "1111". By applying "Data-in" and "Clock" alternatively, binary sequence "1111" was loaded into circuit successfully. And as

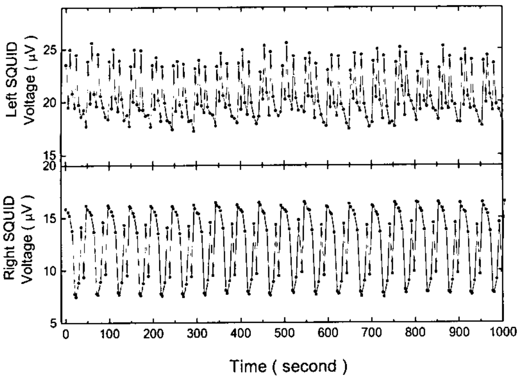

Fig. 7. 20 cycles of the load and shift operation of the shift register for the binary data sequence "1011".

successive clocks applied, the voltage level of left SQUID decreased and that of right SQUID voltage increased monotonously. This implies that the stored quantum flux goes out through the "Data-out" one by one.

We also observed successful shift register operation for the binary data sequence "1011". No error was observed for 20 cycles of the load and shift operation, which is shown in Fig. 7.

For all the data sequences "1000", "1010", "1011", and "1111", we tested load and shift operation for longer time. During more than 12 hours operations, no error was observed for all the sequences.

IV. Summary

We have fabricated a 4-stage shift register using interface-controlled ramp-edge Josephson junction. We observed RSJ-like I-V curves of the Josephson junction at temperatures 45~80K. In order to confirm the proper operation of the shift register, we repeated load and shift operation for the binary data sequences, "1000", "1010", "1011", and "1111" at 58K. Our shift register operated successfully for all the data sequences. By operating the circuit with proper current pulses, we observed no errors during at least 12 hours operation for all the data sequences. These results are better than the shift register that was fabricated on bicrystal substrate before[6].

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