π-π-π SQUIDs に基づく半磁束量子 T フリップフロップ

Half-Flux-Quantum Toggle Flip Flops Based on π-π-π SQUIDs

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Background

The most direct way for SFQ circuits to gain an overwhelming advantage over the CMOS technology in energy efficiency is to reduce critical currents of the Josephson junctions. We have already shown that 0-0-π SQUIDs have a very small nominal critical current ($I_{nominal}$) and that the half-flux-quantum (HFQ) circuits constructed by replacing Josephson junctions in SFQ circuits with 0-0-π SQUIDs are promising to decrease the power consumption further [1, 2]. In the HFQ circuits, the information is coded with the transmission of half-flux-quantum ($\Phi_0/2$) due to the intrinsic π-phase shift in 0-0-π SQUIDs, and the operating frequency f can be determined by $f = V/(\Phi_0/2)$, where V represents the average voltage across a 0-0-π SQUID.

Experiment

In this work, we developed a novel fabrication process for HFQ circuits with π-π-π SQUIDs, in which one π-junction with a critical current of $4I_c$ is used for a non-switching phase shifter while the other two π-junctions with critical currents of I_c act as the switching elements. All the π-junctions are un-shunted and fabricated based on the $Nb/Pd_{89}Ni_{11}/Al\text{-}AlO_x/Nb$ (SIFS) multilayer structure. We designed and fabricated HFQ toggle flip-flops (TFFs) based on π-π-π SQUIDs, in which the switching junction had an area of 10 μm×10 μm. Due to the small $I_{nominal}$, ground plane holes, as shown in Fig. 1, were utilized to increase the inductance per unit length to obtain the correct operation [3].

Result

The critical current density, I_c, and characteristic voltage of π junction are about 20 A/cm^2, 1 μA, and 30 μV, respectively. According to the simulation, the bias margin of HFQ TFF is about ±20%. The measurement was done with high-frequency pulse trains, and the output voltage (V_{out}) measured at 4.2 K was exactly half of the input voltage (V_{in}), indicating the correct divide-by-two operation up to 18 GHz, as shown in Fig. 2.

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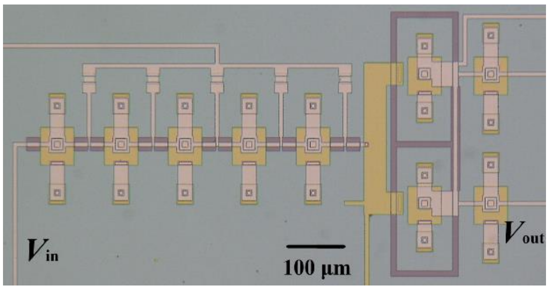

Fig. 1 HFQ TFF fabricated with π-π-π SQUIDs.

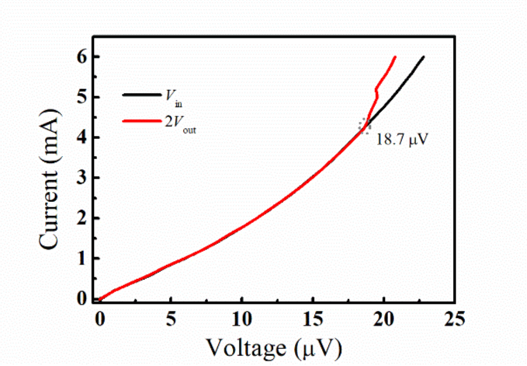

Fig. 2 Input and output voltages of HFQ TFF.