MgB_2 Rapid Single Flux Quantum Toggle Flip Flop Circuit

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September 23, 2013 (HP64) When superconductivity at 39 K was discovered in MgB_2 in 2001, its potential impact in superconducting electronics was immediately recognized.[1] The relatively high T_c would allow superconducting devices such as SQUID detectors and superconducting digital circuits to operate at above 20 K, a temperature attainable by smaller, more efficient and cheaper cryocoolers than required by the Nb-based devices and circuits. The larger energy gaps in MgB_2 could potentially lead to higher operating frequency than in Nb-based digital circuits. The recent work on superconducting MgB_2 rapid single flux quantum toggle flip flop circuits[2] presents the first demonstration of a superconducting digital circuit utilizing MgB_2 Josephson junctions. The TFF circuits were shown to operate up to 180 GHz at low temperatures and 65 GHz at 20 K.

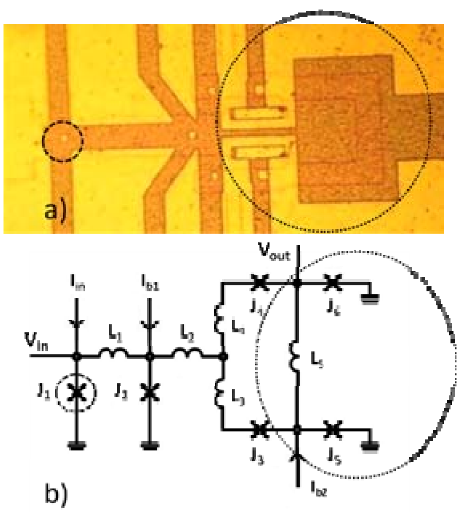

Figure 1. Optical image (a) and schematic diagram(b) of the toggle flip flop circuit.

The circuits consisted of six self-shunted $MgB_2/MgO/MgB_2$ Josephson junctions and five MgB_2 microstrip inductors (see Fig. 1). They were made using a multilayer process with three MgB_2 layers and MgO as both barrier and insulating layer. Two MgB_2 layers are for the $MgB_2/MgO/MgB_2$ junctions and one for the wiring layer. Both of the MgB_2 electrode layers also function as ground planes for the inductors in the opposing layers. The MgB_2 layers were grown by hybrid physical chemical vapor deposition[3] and the MgO layers by RF magnetron sputtering from a MgO ceramic target. The junction sizes were either 4 μm x 4 μm or 5 μm x 5 μm. The $MgB_2/MgO/MgB_2$ junctions are normally hysteretic at low temperatures and become RSJ-like around 20 K,[4] but in one of the circuits they were already self-shunted at 3.2 K. The I_c spread of the junctions was within the simulated allowable margin for the circuit of ±15%.

The operation of the TFF circuit was tested by measuring the V_{in} and V_{out} of the circuit as the input current I_{in} was scanned. Figure 2 shows the results for two circuits. Temperature and bias currents were adjusted in order to achieve the frequency division operation. Figure 2(a) is the result of one circuit measured at 3.2 K, which shows that V_{in} and $2V_{out}$ overlap up to about 0.37 mV before they separate with each other, indicating that the TFF functioned up to a Josephson frequency of about 180 GHz. Figure 2(b) is for another circuit measured at 12.5 K, with the range where V_{in} and $2V_{out}$ overlap up to about 0.2 mV, corresponding to a Josephson frequency of 100 GHz. Figure 3 shows the operating region, where $V_{in} = 2V_{out}$, at 20 K for Circuit B at different bias currents and input voltages. The experimental ranges of temperature and bias parameters were in general agreement with the design parameters within the allowable margins. The best operating frequencies were 180 GHz at low temperatures and 65 GHz at 20 K.

The work demonstrates the viability of MgB_2 for superconducting integrated circuits. Further improvements by adding a ground plane and improving junction parameter control will no doubt lead to more complex MgB_2 RSFQ circuits with better performances.

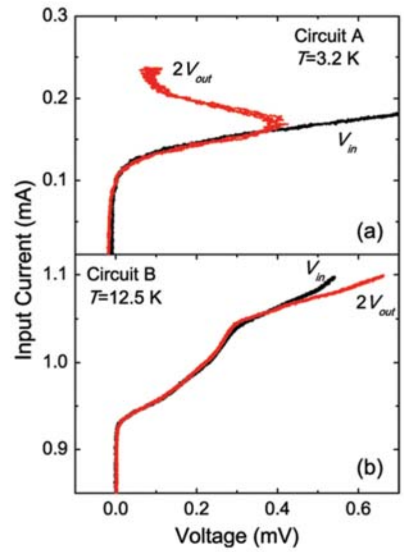

Figure 2. Input voltage V_{in} and twice the output voltage $2V_{out}$ versus input current I_{in} for (a) circuit A at 3.2 K, and (b) circuit B at 12.5 K.

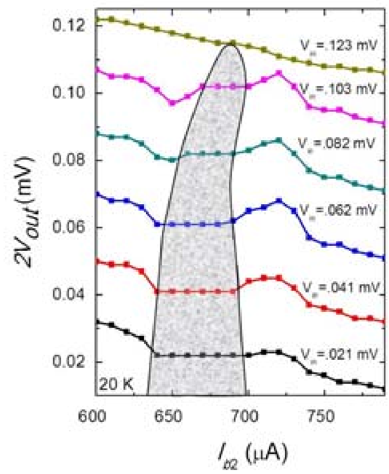

Figure 3 Operating region at 20 K, indicated by the shaded area, for Circuit B at different input voltages.

References

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