Nanoscale Resistance Switches for Radio Frequency Applications

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High performance reconfigurable switches are critical components for radio frequency (RF) circuits. Current devices based on microelectromechanical system (MEMS) and phase change memory (PCM) suffer from disadvantages such as high power consumption, large size, low speed, and limited reliability.[1, 2] In this work, we present a low-power, nanoscale resistance switch for RF applications, with a typical 3 dB insertion loss at ON and 22 dB isolation at OFF state up to 67 GHz.

The device used in this study consisted of a pair of Ag-Au electrodes 50 nm apart on a Si substrate with a 100 nm thick thermally grown SiO_2 layer. ON and OFF switching was implemented through the formation and rupture of an Ag metallic filament between the two electrodes under electric field. To fabricate the devices, 280 nm thick PMMA resist was first spin-coated on the substrate. Pairs of 10 nm Ni/40 nm Au pads separated by a 50 nm wide gap were fabricated by electron beam lithography (EBL) and metal evaporation at a 40^o oblique angle (Figs. 1A, 1B). 45 nm thick Ag was then evaporated at a normal angle, followed by a liftoff in acetone, which concluded the device fabrication (Figs. 1C, D). Figure 2 shows a typical SEM image of the nanoscale device, with Au/Ni on the right and Ag on the left.

During DC measurement, the Ag electrode was biased while the Au electrode was grounded. Devices with such lateral structure exhibited low operation voltages and high ON/OFF ratio. As shown in a typical IV curve (Figure 3), the device was switched ON at 0.9 V and OFF at -0.5 V, with a $>10^7$ ON/OFF ratio, and ON state resistance (R_{ON}) of 28 Ω (both read at 0.1 V). RF measurements were conducted using an Agilent N5247A Vector Network Analyzer (VNA), with an output power of up to 5 dBm. The typical S21 at ON and OFF states are plotted in Figure 4. An ON state insertion loss of 3 dB and an OFF state isolation of larger than 22 dB were achieved up to 67 GHz for this device.

Reported RF measurements were referenced to the contact pads and included significant parasitic effects due to the doped silicon substrate. Thus, we believe that the intrinsic performance of the device is significantly better than these preliminary measurements imply. For devices of smaller gap sizes on better insulating substrate, we expect an ON state insertion loss <1 dB and OFF state isolation >20 dB up to 110 GHz, achieving a cutoff frequency ($f_c = 1/2\pi R_{ON}C_{OFF}$) beyond 5 THz.

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1 Wen, C. Y. *et al. IEEE Trans. Electron Devices* **60,** 3979-3988 (1971).
2 Nessel, J. A. *et al. Microwave Symposium Digest, IEEE MTT-S International*. 1051-1054 (2008).

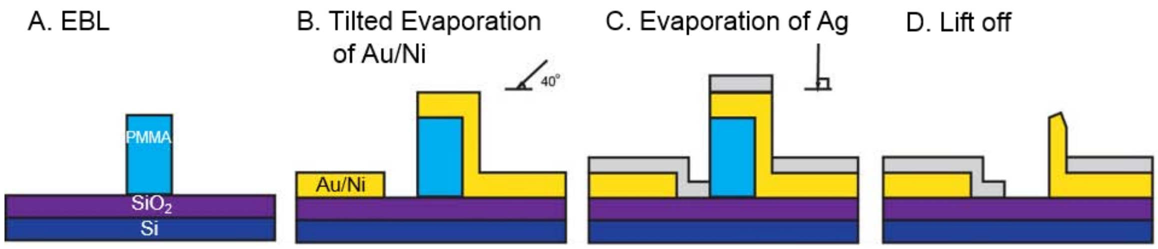

Figure 1: Fabrication procedure of the nanoscale resistance switches. A 50 nm wide, about 200 nm high PMMA wire patterned by EBL (A) is used as the shadow mask for 10 nm Ni/40 nm Au deposition with an 40° oblique angle (B). A layer of 45 nm Ag is then deposited at a normal angle (C), followed by liftoff in acetone (D).

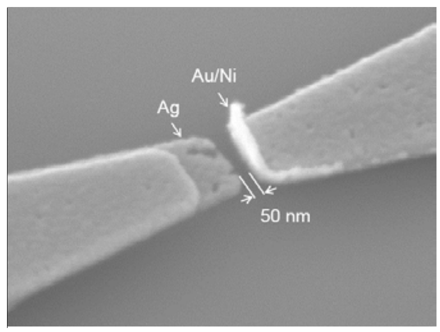

Figure 2: SEM image of the 50 nm gap between cathode of Au/Ni (right) and anode of Ag (left).

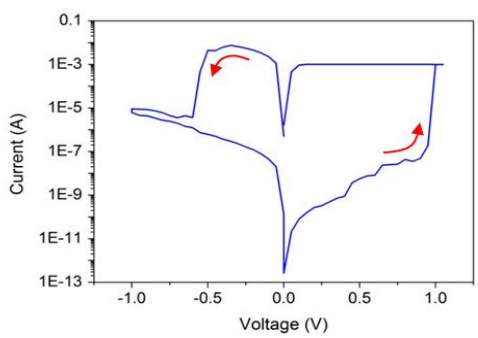

Figure 3: Typical bipolar switching behavior of the resistance switch. The device is set to ON state of 28 Ω at 0.9 V and reset to OFF state at -0.5 V.

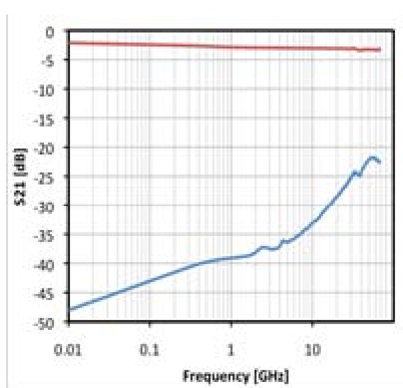

Figure 4: RF measurement result of the resistive switch. Insertion loss of 3 dB and isolation of 22 dB are observed.