RF Reflectometry Measurement of Gap-closing MEMS for Adiabatic Reversible Computing

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Adiabatic reversible computing is a promising approach to energy-efficient computing that can dramatically reduce heat dissipation by switching circuits slowly, relative to their RC time constants, introducing a trade-off between energy and speed. CMOS circuits are ultimately limited by leakage since transistors do not turn completely off. MEMS relays have been explored as alternative devices to eliminate leakage but are limited by the degradation of current-carrying contacts[1]. We present the nanofabrication of MEMS gap-closing variable capacitors for reversible computing. Here, capacitors can be used instead of transistors to implement reversible computing as proposed by Adiabatic Capacitive Logic[2] (ACL). In ACL, variable capacitors are connected to static capacitors to create pull-up and pull-down networks that in turn create digital gates. Since capacitors do not need make-and-break electrical contacts, they are not limited by the degradation of contacts.

The MEMS devices have two separate capacitors: one to apply an electrostatic force to move down the cantilever, and another to achieve adiabatic reversible computing. The devices are fabricated on silicon wafers covered with a silicon nitride layer as a base insulator, the top view of the devices is presented in Figure 1(a), and a cross section is presented in Figure 1(b). The bottom electrodes are made of TiN, that is sputtered, patterned by optical lithography using an i-line stepper, and etched. Then a sacrificial layer of SiO2 is deposited, patterned, and dry etched to open a hole in the oxide. Polysilicon is then deposited by low-pressure chemical vapor deposition (LPCVD) and doped. Next, a slot is etched in the polysilicon cantilever, and SiNx is deposited by LPCVD to fill the slot, which is then patterned and etched. Finally, the moving mechanical structures are released using vapor HF to remove the SiO2 layer under the cantilever.

Radio frequency reflectometry is used to measure the capacitance change in our devices as presented in Figure 2(a), while a measurement of the reflected signal is presented in Figure 2(b). Our devices can also be used as relays to verify their functionality as presented in Figure 3(a). The measured change in the S11 parameter that corresponds to a change in the capacitance of the system as the device moves down is presented in Figure 3(b). This agrees with the capacitance increase of our devices calculated through COMSOL simulations.

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[1] S. Rana *et al.*, *Nature Communications*, **11**, 1181, (2020).
[2] H. Samaali *et al.*, *Nano Energy*, **55**, 277-287, (2019).

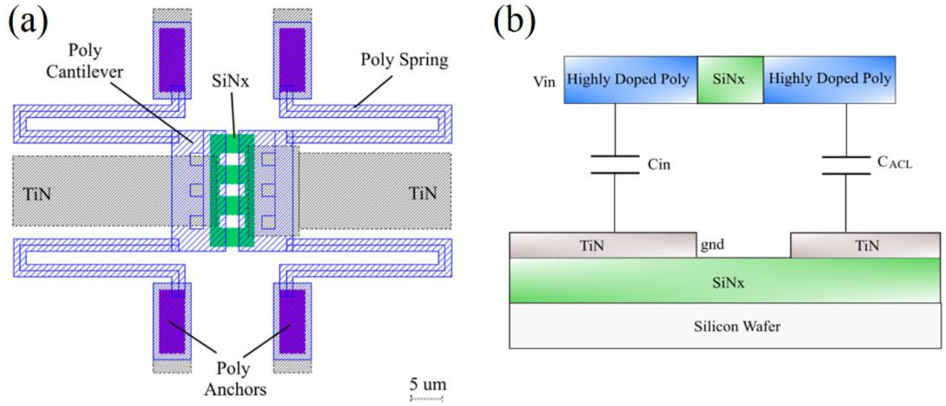

Figure 1: (a) Top view of MEMS variable capacitors. (b) Cross-section diagram.

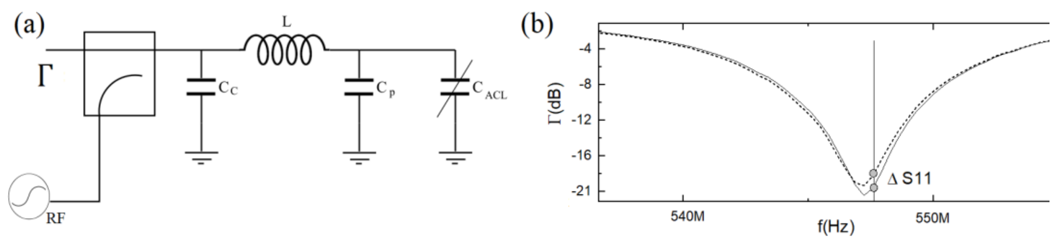

Figure 2: (a) RF reflectometry system to measure change capacitance includes a matching network with a calibration capacitor, and inductor, a parasitic capacitor, and a variable ACL capacitor. (b) Example of change in S11 parameter for a determined frequency as the capacitance increases.

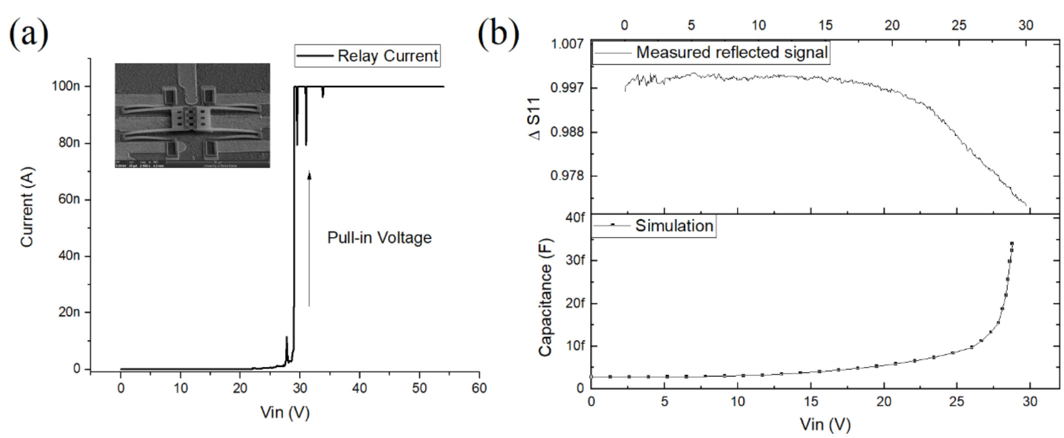

Figure 3: (a) Measured current of device (inset) operated as relay shows the cantilever moves completely down at a pull-in voltage of 30 V. (b) Measured change in S11 parameter, normalized to 1 when the cantilever is in the up position, shows good agreement with capacitance increase calculated through COMSOL simulations.