Accurate measurement of the internal potential in two capacitors connected in series for studying Negative Capacitance effects

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1. Introduction:

The channel potential amplification by a ferroelectric(FE) gate oxide, namely a negative capacitance (NC) effect [1], needs to be experimentally verified before showing steep subthreshold swing. An accurate measurement of the internal potential at the floating node in two capacitors connected in series may provide a more direct evidence. In this paper, we discuss how to measure the internal potential and its significance on the NC demonstration so far reported.

2. Results and discussion

In principle, the resistivity of capacitor is infinite. However, even a best capacitor has a leakage with a finite resistivity in reality. Thus, in the simple series connection of two capacitors, two RC components should be considered in the equivalent circuit (**Fig. 1**). The finite input impedance in the measurement system (*R2′*) actually brings a leakage as well. Therefore, the internal potential on the floating terminal, *V2*, can be formulated as

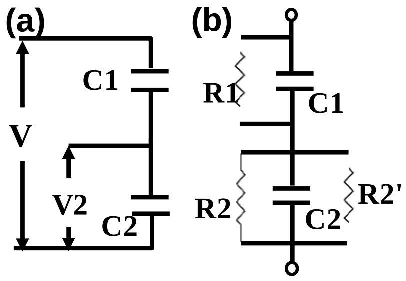

Fig.1 (a) Schematics and (b) equivalent circuit of setup for measurement of internal potential of series capacitors

$$V2 = V\left(\frac{C1}{C1+C2} - \frac{R2^*}{R1+R2^*}\right)e^{-\frac{t}{\tau}} + V\frac{R2^*}{R1+R2^*}, \quad \frac{1}{R2^*} = \frac{1}{R2} + \frac{1}{R2'}, \quad \tau = \frac{C1+C2}{\frac{1}{R2} + \frac{1}{R2^*}} \quad (1)$$

Fig. 2 show how measurement time *t* (frequency) and *R* affect *V2* experimentally. Both calculated and experimental results suggest that an accurate measurement of *V2* can be only achieved with $t \ll \tau$.

In addition, it has been expected that a small capacitance of dielectric, is needed to stabilize NC of FE material [2]. But small C lowers τ. According to Eq(1), it is hard to measure expected *V2* when τ are smaller than 10s in DC circuit with the time scale of second. We achieved the accurate DC-measurement of *V2* with *C2* down to 1pF by choosing low leakage capacitors (~10^{12} Ω) and ultra-high impedance measurement system (10^{16}Ω) (**Fig. 3)**. The results with normal measurement system (~10^{10}Ω) in which expected *V2* could not be obtained is included in Fig. 3(c) for a comparison.

3. Conclusions

Easy measurements of the floating node potential will mislead the understanding of NC effects, although S-factor seems to be lower than 60 mV/dec. We should check the time response in the circuit employed for NC effect measurements.

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References: [1] A. I. Khan *et al*, Nature materials, 14 182 (2015) [2] S. Salahuddin *et al*, Nano Lett., **8**, 405(2008).

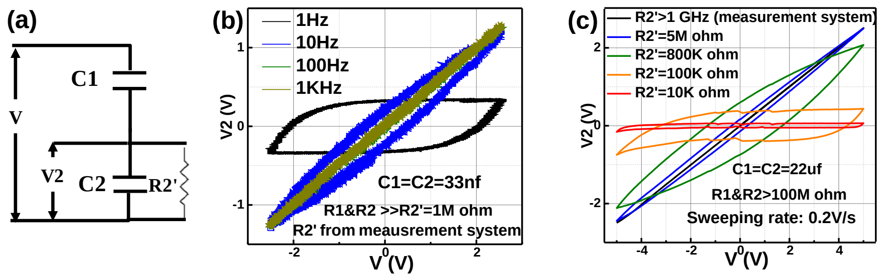

Fig.2 (a) Schematics of internal potential measurement. **(b)**Results of C1=C2=33nf with changing *t* (frequency), the impedance from measurement system dominant leakage.τ=2R2'C=66ms.**(c)** Results of C1=C2=22uf with changing R2', R2' is externally connected resistor smaller than impedance of measurement system in this case.

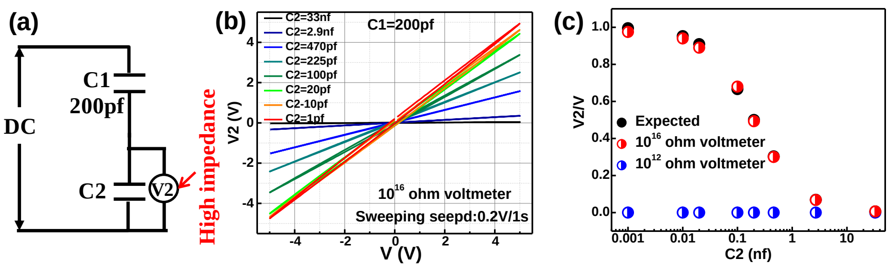

Fig.3 V2 measurement with C1 of 200pf and C2 changing from 33nf to 1pf by using high impedance measurement system: **(a)** schematics of setup, **(b)** V2 as a function of V, and **(c)** V2/V as a function of C2. V2 has been measured as expected while it cannot be measured with relative low impedance system.