Student Paper

Domain-Wall Spintronic Memristor for Capacitance and Inductance Sensing

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The dynamic properties of a propagating magnetic domain-wall in a magnetic device are strongly affected by the device geometry [1]. Domain-wall spintronic memristors (Fig.1) [2] exhibit therefore a geometry dependent memristive behavior. We propose novel capacitance and inductance sensing schemes using two different spatial shapes of domain-wall spintronic memristors and also a novel nanoelectronic device (Fig.2), which is capable of fast and simultaneous capacitance (in the pico-farad range) and inductance (in the micro-henry range) sensing. The device reduces the problem of sensing capacitance and inductance to a simple resistance measurement. From the definition of the memristor [3], [4] through its constitutive relation, it can be shown that when the derivative of the memristance/memductance to charge/flux is constant (Fig.4), the memristor is suited for capacitance/inductance measurement. The capacitance/inductance of a capacitor/an inductor connected in series/parallel to the memristor is determined by measuring changes in the memristance/memductance, which is determined by the domain-wall position [2] (Fig.3), and the voltage/current across/through the capacitor/inductor.

Fig. 5a/Fig.6a show the I-V curves of the memristor for different capacitances/inductances excited by a step voltage/current pulse. Fig.5b/Fig.6b and Fig.5c/Fig.6c illustrate the memristor's nonlinear behavior as a function of the capacitance/inductance value. It proves that one can determine the capacitance/inductance within a time interval much shorter than the charging time constant (Fig.5b/Fig.6b).

The sensitivity of the proposed memristive sensing scheme is determined by the value of the memristance modulation with respect to the charge passed through the memristor. The amount of charge needed to change the memristance from its minimum to its maximum value for HP's titanium dioxide memristors [5] is in the range of micro-coulombs, but it is in the range of nano-coulombs to pico-coulombs (extracted from [6]) for domain-wall spintronic memristors. We note that titanium dioxide memristors are suited for capacitance sensing and our results indicate that (time-varying) capacitances in the range from micro-farads to nano-farads can be measured. Spintronic memristors are therefore promising for measuring capacitances of 3-6 orders of magnitude smaller than those measured by titanium dioxide memristors.

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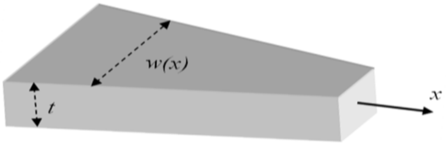

Fig. 1. Domain-wall spintronic memristor (DWM): a thin film element with spin torque induced domain-wall motion [1]. The constitutive relation is $\varphi = A\, q^{(1-\rho k)/(\rho+1)}$ where q is the time integral of the current passed through the device, φ is the time integral of the voltage across the device, A is a constant coefficient, ρ determines the spatial dependence of w as $w(x) = \tilde{w}(x/\tilde{x})^{\rho}$, which "tild" symbol represents a quantity when the domain-wall position x is $\tilde{x}$. The parameter k (=2.2 [7]) defines the domain-wall mobility μ scaling with the aspect ratio $\mu \sim (w/t)^{k}$.

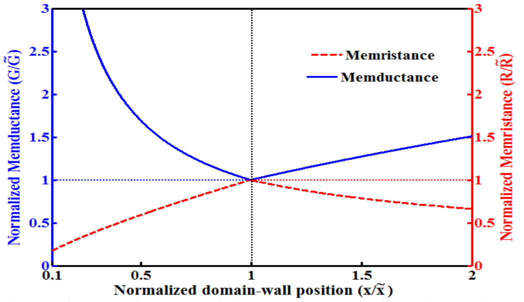

Fig. 3. The memristance and the memductance of the device shown in Fig.2 as a function of x. For $x < \tilde{x}$ and $x > \tilde{x}$ the constitutive relations are $\varphi = Aq^2$ and $q = A'\varphi^2$ respectively, so $R(q) = d\varphi(q)/dq = 2Aq$ and $G(\varphi) = dq(\varphi)/d\varphi = 2A'\varphi$. We define $\tilde{R}$ and $\tilde{G}$ as the memristance and the memductance of the device, when the domain-wall position x is $\tilde{x}$.

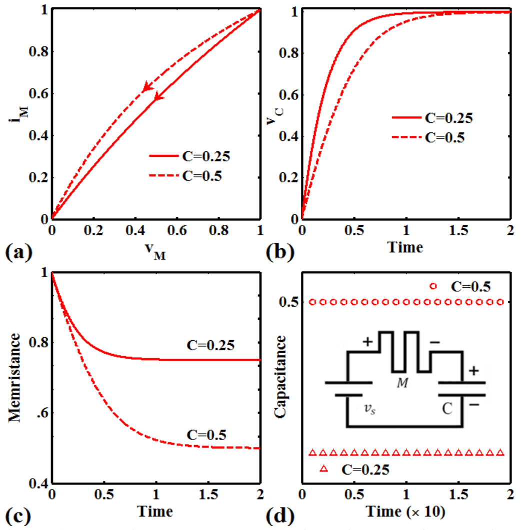

Fig. 5. (**a**) Memristor I-V curves, (**b**) the voltage on the capacitor, (**c**) the memristance, and (**d**) the electric circuit and the measured capacitances. The applied voltage is $v_0 u(t)$ (unit step $u(t) = 0$ for $t<0$ and 1 for $t>0$) and all axes are dimensionless, with voltage, current, memristance, time, and capacitance expressed in units of v_0, $i_0 \equiv v_0/\tilde{R}$, $\tilde{R}$, $t_0 \equiv \tilde{q}\tilde{R}/v_0$, and $C_0 \equiv \tilde{q}/v_0$.

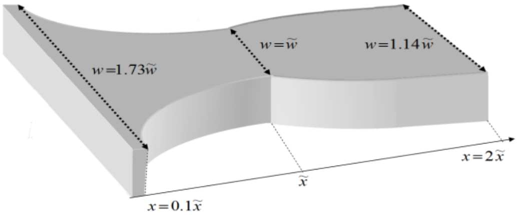

Fig. 2. Proposed domain-wall spintronic memristor. ($w = \tilde{w}(x/\tilde{x})^{-0.24}$ for $x < \tilde{x}$ and $w = \tilde{w}(x/\tilde{x})^{0.19}$ for $x > \tilde{x}$).

According to the constitutive relation of a domain-wall spintronic memristor [2], the device with the proposed geometry is suited for both capacitance (when the domain-wall position $x < \tilde{x}$) and inductance (when $x > \tilde{x}$) sensing.

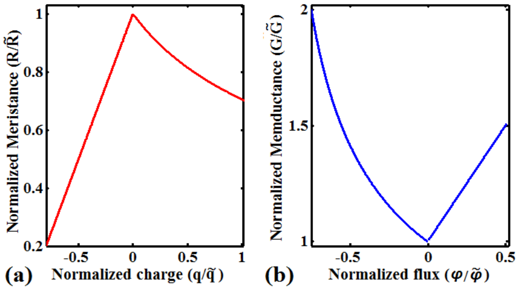

Fig. 4. (**a**) The memristance of the device (R) plotted as a function of charge q. The term $dR(q)/dq$ is constant for $q<0$ ($x < \tilde{x}$). (**b**) The memductance of the device (G) plotted as a function of flux φ. The term $dG(\varphi)/d\varphi$ is constant for $\varphi > 0$ ($x > \tilde{x}$). $\tilde{q}$ and $\tilde{\varphi}$ are defined as $\tilde{q} \equiv \tilde{R}/(2A)$ and $\tilde{\varphi} \equiv \tilde{G}/(2A')$.

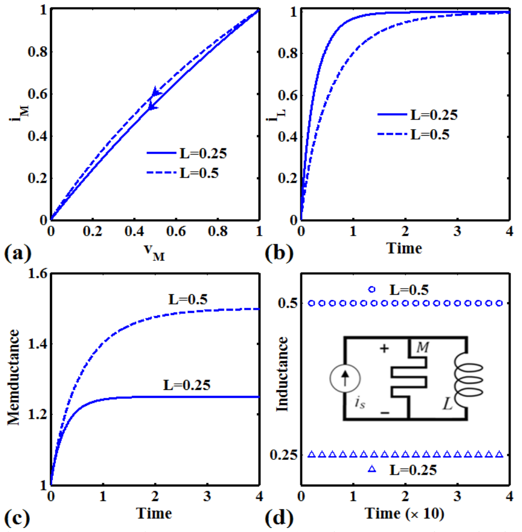

Fig. 6. (**a**) Memristor I-V curves, (**b**) the current through the inductor, (**c**) the memductance, and (**d**) the electric circuit and the measured inductances. The applied current is $i_0 u(t)$ (unit step $u(t)=0$ for $t<0$ and 1 for $t>0$) and all axes are dimensionless, with current, voltage, memductance, time, and inductance expressed in units of i_0, $v_0 \equiv i_0/\tilde{G}$, $\tilde{G}$, $t_0 \equiv \tilde{\varphi}\tilde{G}/i_0$, and $L_0 \equiv \tilde{\varphi}/i_0$.