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Enhancement of the gasistor device by separation of the gas sensing and the memristive cells

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Summary:
The gasistor is a device, which combines gas sensing and resistive switching in a single capacitor-like metal/metal oxide/metal cell. It works as a gas sensor with memristive memory or as a thyristor-like switch triggered by a change in the target gas concentration. The same metal oxide layer and the same cell used for gas-sensing is also used for resistive switching. The mutual entanglement of their fabrication parameters impedes the ability to separately adjust the two functionalities. In this work the two parts (sensor and memristor) are developed separately, allowing for their individual tuning, targeting specific gas concentration and improving the sensitivity of the gasistor device.

Keywords: Gasistor, hydrogen gas sensor, memristor, titanium dioxide, nanoporous electrode

The gasistor

The gasistor[1] is a device, which combines gas sensing and resistive switching in a single capacitor-like metal/metal oxide/metal cell. It has the ability to switch from high-resistance to low-resistance state when the concentration of a reducing gas in its vicinity reaches a pre-set value. The structure of the device is equivalent to chemiresistive gas sensor in a capacitor-like Pt/TiO_2/Pt arrangement[2]. The sensor reacts to the presence of hydrogen gas in an oxidizing atmosphere (air). The memristive (resistive switching) functionality is allowed by a conductive filament formed by soft dielectric breakdown in the TiO_2. The region of conductive filament is rich in oxygen vacancies and can be considered gas-insensitive. The device can thus be modelled as being composed of 2 separate devices – non-memristive gas sensor and gas-insensitive memristor - connected in parallel. The key feature of the memristor is its hysteretic I(V) curve, which indicates the existence of at least two resistance states. The transition between those states can be continuous or abrupt. The memristors used in the gasistor tend to switch abruptly. The switch is induced by high enough electric field in the memristor, i.e. the voltage applied to its terminals. In the case of switching just between two resistance states, those states are LRS (low resistance state) and HRS (high resistance state). The threshold voltages are V_{set} - voltage required to switch the device from HRS to LRS and V_{reset} required to switch from LRS to HRS. In the case of bipolar resistive switching, these two voltages are in opposite polarities (this is also the case of a gasistor). The model [1] assumes that in the HRS and LRS the conductive filament is shortened or prolonged, respectively.

The working principle of gasistor assumes comparable resistances of the hydrogen gas sensor at studied conditions[1] (hydrogen gas concentration, temperature and humidity) and the memristor in the HRS. The process of the gas-induced resistive switching requires the gasistor to be biased by a suitable constant current, the hydrogen gas concentration to be above desired switching concentration and the memristor part to be in the HRS. After that, when the hydrogen concentration drops, the resistance of the gas sensing part increases, along with voltage applied to the gasistor. When the voltage reaches V_{set}, the memristive part switches from HRS to LRS. The LRS is stable until it is re-set on purpose in the opposite polarity, thus effectively providing the gasistor with a long-term memory function.

The separation of the gas sensing and the memristive cells

However, the above-mentioned condition of resistances of the gas-sensing and memristive part being similar is difficult to achieve, especially for lower hydrogen concentrations. The base resistance of gas sensor

(subjected to air at room temperature) is typically higher than 10^{12} Ω, while the memristor after electroforming in the HRS reaches resistances of up to 10^{7} Ω[1]. The adjustment of such devices simultaneously is a challenging task. Therefore, this work focuses on the isolation of the two parts (Fig.1) and their separate characterization. We show that we can improve the gas sensor by implementing large-scale (> 100x100 μm^2) nanoporous top electrode, as the sensing process occurs at the edges of the top electrode, since the Pt layer is almost impermeable to hydrogen and water vapor. Implementation of the large-scale nanoporous top electrode effectively decreases the base resistance, while maintaining the sensitivity. Increasing the area of the memristor would be undesirable, as the increased capacity leads to several problems and the electroforming on such structures often leads to lower resistances. The opposite can be done to increase the resistance of the HRS. Separating the cells also allows us to isolate the memristive part from the surrounding atmosphere by a passivation SiO_2 layer (Fig.2), which will allow easier analysis of the device functionality. Fine-tuning of both devices separately will lead to a gasistor device targeting specific gas concentrations, with higher sensitivity.

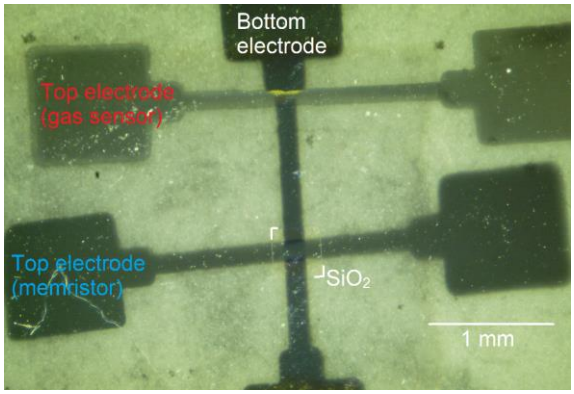

Fig.1: Hydrogen gas sensor and memristor with an equal area (~150 × 150 μm)

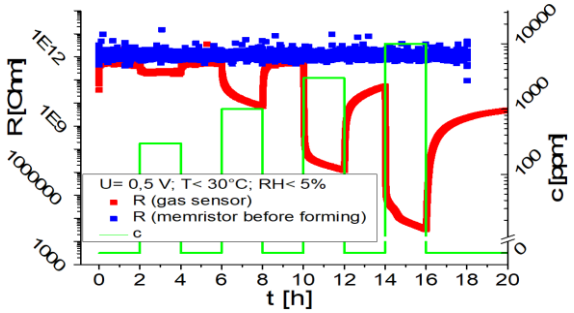

Fig.2: Resistance response to hydrogen concentration (green) of: separate memristor passivated by SiO_2 layer (blue) and gas sensor with nanoporous top electrode (red) in an arrangement as shown in Fig.1.

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