Innovationscampus Elektronik und Mikrosensorik Cottbus: Rational design and development of room temperature H_2 sensors compatible with CMOS technology for the coming renewable H_2 economy

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1. Introduction

The transition towards a new, renewable energy system based on green energy vectors, such as hydrogen, requires not only direct energy conversion and storage systems, but also the development of auxiliary components, such as highly sensitive hydrogen gas sensors integrated into mass devices that operate at ambient conditions. Despite the recent advances in nanostructured metal oxide thin films in terms of simple fabrication processes and compatibility with integrated circuits [1,2], high sensitivity and short response/recovery times usually require the use of expensive noble metals or elevated temperatures (>250 ºC), which results in high power consumption and poor long-term stability [3].

Within the iCampµs AP.4.1 work package, our groups have been working on the development of a novel resistive hydrogen gas sensor based on thin and ultrathin cerium oxide (CeO_x) films, compatible with complementary metal oxide semiconductor (CMOS) technology and capable of operating at room temperature. Here, we show a multidisciplinary bottom-up approach combining different work areas for the sensor development, such as sensor architecture, sensing mechanism and deposition strategy of the active layer, electrical contact design depending on the desired electrical output, and fast testing under controlled environments.

2. Experimental methods

The atomic layer deposition (ALD) processes were performed in a homemade ALD reactor combined with X-ray photoelectron spectroscopy (XPS) for *in-situ* analysis at the BTU [4]. CeO_x ultrathin films were prepared on Si-based nanostructured substrates using commercial the organometallic precursor $Ce(thd)_4$ and ozone (O_3/O_2) as co-reactant, reaching a steady growth of ~0.15 Å/cycle. As an alternative, ceria flat thin films were grown using magnetron sputtering. *Ex-situ* transmission electron microscopy (TEM) and energy dispersive X-ray fluorescence (EDX) measurements were performed at the IHP with a FEI Tecnai Osiris instrument operated at 200 kV. Complementary measurements have been done in multiple international synchrotron facilities, including BESSY II (Berlin), ALBA (Barcelona), and ESRF (Grenoble), as well as the CERIC-ERIC labs (Prague) and the Wrocław University of Science and Technology.

3. Results and discussion

The selection of ceria as the active material is based on the facile exchange of the cation oxidation states, Ce^{3+} and Ce^{4+}, under reducing and oxidizing atmospheres, which is accompanied by the creation or annihilation of oxygen vacancies and defects in the surface and bulk regions under varying redox environmental conditions, thus leading to changes in electrical conductivity. Moreover, ceria can easily be deposited by a variety of physical and chemical deposition techniques, ensuring precise control of crystallinity, microstructure, and composition to tailor its physicochemical properties and, thus, its response and selectivity to different gases. In particular, a promising alternative in terms of synthesis control would be the growth of conformal and homogeneous ultrathin films (<20 nm) on nanostructured Si-based substrates by atomic layer deposition, which due to its self-limiting nature would ensure deposition control at the atomic level. The latter idea has been intensively explored, giving rise to promising preliminary results that prove the high reactivity of ALD-ceria ultrathin films towards H_2 under room conditions in the presence of oxidizing species.

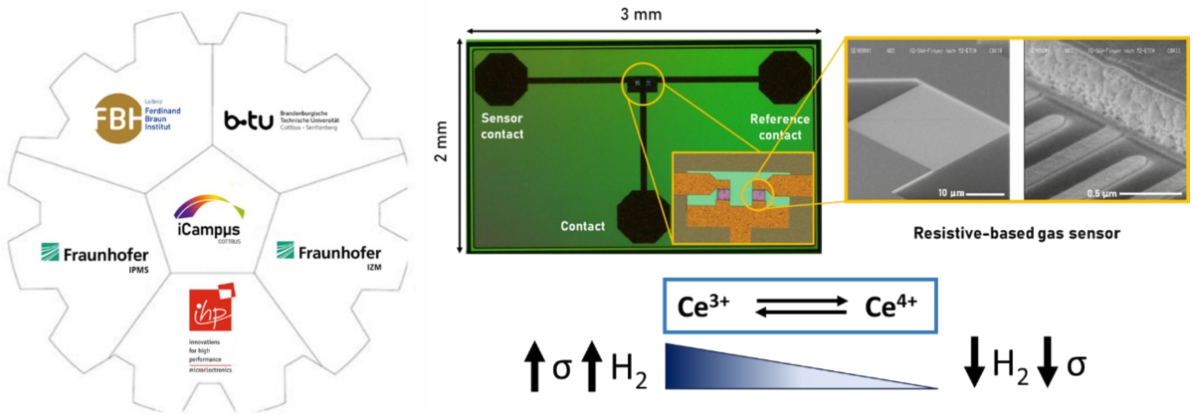

Figure 1. From left to right: organization diagram of the iCampμs partners; Optical image of the proposed H_2 sensor, with SEM images zooming the finger electrodes. On the bottom, scheme of the physical principle ruling the ceria-based resistive sensor.

Moreover, the extended network developed during the last four years has allowed us to multiply our research resources and accelerate the achievement of promising results that would have taken more time given the existing capabilities at the iCampμs partners' facilities.

References

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