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Dry transfer print process of SnO_2 nanowires for gas sensor manufacturing

F. Sosada-Ludwikowska, *R. Wimmer-Teubenbacher, A. Köck*
Materials Center Leoben Forschung GmbH, Leoben Austria
florentyna.sosada-ludwikowska@mcl.at

Abstract

SnO_2 nanowires have been synthesized and implemented on Si-based sensors with gold inter-digital electrode structures (IDES). A dry transfer printing technology employing a PDMS-stamp has been used to fabricate multi-nanowire gas sensing devices with good reproducibility. Successful operation of the SnO_2 nanowire-based gas sensors has been demonstrated which show a high sensitivity to hydrogen sulfide. This dry transfer printing technique might be the technology of choice for controlled fabrication of nanowire-based devices and could be easily adapted for industrial production.

Key words: transfer, nanowires, metal oxide, printing, PDMS

Metal oxide nanomaterial based gas sensors are of great interest due to high sensitivity, easy production and simple electrical measurements of these materials. [1] Missing link from the nanomaterial processing to operating chemical sensing devices is a reliable implementation technology for transferring nanostructures to the gas sensing substrate. In this work a transfer printing process is presented which has been employed for integration of SnO_2 nanowires on gold electrode structures.

Metal Oxide Nanowires Synthesis

The SnO_2 nanowires were prepared by a specific two-step synthesis. [2] 400 nm SnO_2 and 40 nm Cu thin layers were deposited on two separate Si-substrates (size 2 x 2 cm^2) by spray pyrolysis and sputtering techniques, respectively. Secondly those two layers were mounted parallel to each other (“face to face”) with the SnO_2-coated substrate down and the Cu-substrate on top. An annealing process in Argon atmosphere at 900°C results in the growth of SnO_2 nanowires on the Cu-coated Si-substrate. Dimensions of the SnO_2 nanowires on metal-catalyst substrate were 50-200 nm in diameter and 10-100 µm in length.

Dry Transfer Process

For the transfer process a PDMS stamp was employed. The PDMS stamp was produced by a Dow Corning Sylgard 184 standard recipe (10:1). Small 5x5 mm^2 pieces were used to manually transfer the SnO_2 nanowires from the “donor” substrate to the Si-based gas sensor structure with Au-IDES as electric contacts (Fig. 1). Width of the Au-electrodes is 10 µm, as well as the distance between the electrodes. The SnO_2 nanowires electrically cross-connect the electrode structures and enable measurement of the resistivity. The final sensor is a multi-nanowire device with a few hundred of SnO_2-nanowires in parallel.

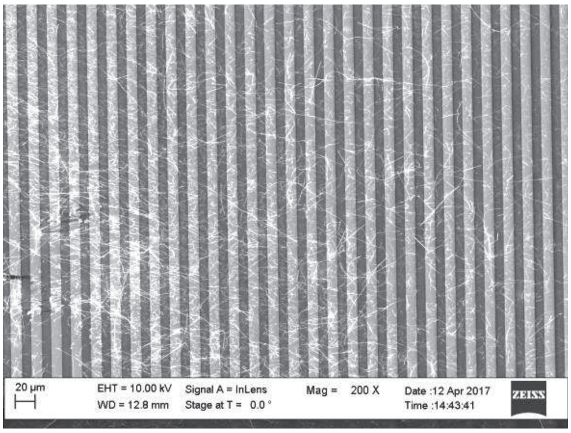

Fig. 1. Printed SnO_2 NWs on the Au-IDES structure.

Gas measurements

The Si-based gas sensors (Fig. 2) were glued on micro heaters (10×2 Pt 6.8 Delta-R GmbH) and thermocouple (4×1 Pt100, Delta-R GmbH) and bonded on a specific chip carrier (mb-Technologies GmbH).

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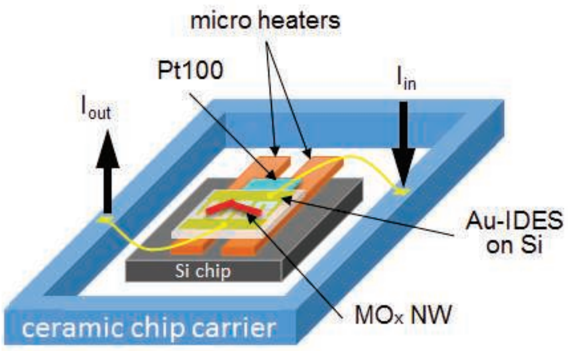

Fig. 2 Si-based gas sensor device with SnO_2 NWs on the Au-IDES structure.

Gas measurements were performed in an automated gas measurement setup. Synthetic air (80% N_2, 20% O_2) was used as background gas and the flow was kept constant at 100 sccm for all gas sensing experiments. The change of resistance was measured in constant current mode (10 nA) and in different concentrations of H_2S: 10, 100, 1000 ppb. The temperature of the gas sensors devices was kept constant at 400°C; the gas sensing performance was studied at three different humidity levels: 25%, 50% and 75%. Sensitivity was calculated as follows:

$$S = \frac{R_{air} - R_{gas}}{R_{air}}$$

Three different gas sensors were produced by the same dry transfer technique in order to evaluate device reproducibility. The gas response for each of them is showed in Fig. 3.

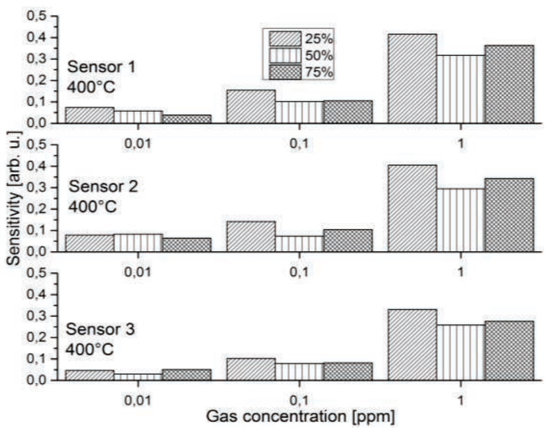

Fig. 3. SnO_2 NWs-based gas sensor sensitivities (H_2S) for three different sensors produced by the same transfer method.

The sensor signal of sensor 1, for example, at 25% rh is 7.3%, 15.5%, and 41.6% for 10 ppb, 100 ppb and 1000 ppb concentration, respectively. The sensor device, however, shows some cross sensitivity to water, which can be improved by employing Au-nanoparticles as functionalization.

The sensitivity values for each of the gas concentration for all three Si-based gas sensors are comparable which demonstrates good reproducibility of the dry transfer printing technique. Big advantage of this technology is that no organic (or other) solvents have to be employed, which might be detrimental for the gas sensor performance. Even performed manually, this method shows high potential to manufacture simply and by low-cost nanowire-based chemical sensor devices. The SnO_2--nanowire synthesis process, which is presently performed on 2 x 2 cm^2 sized samples, could be up-scaled to wafer size. We have already shown that this print transfer technique can be applied also to other types of MO_x NWs, such as CuO-nanowires [3]. Transfer printing of ZnO nanowires should be also feasible. For well-defined transfer from the "donor" substrate (coated with MO_x nanowires) to a CMOS-based micro-hotplate device, for example, a nanoimprinting tool might be employed. This might be the technology of choice for implementing different types of MO_x nanowires on micro-hotplate arrays in order to realize multi-gas sensing devices. This work is presently under progress.

Acknowledgements

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