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Micro and nanotechnology evolution towards vertical Silicon nanowires for ultra-sensitive gas detection

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Most commercial sensors, using metal oxide as sensitive layer, exhibit sensitivity in the ppm range with low selectivity. A part of our previous work is focused on developing new gas sensor array in a small chip based on microhotplates with four silicon membranes and various nanoscaled sensing materials on top deposited by inkjet printing. Moreover, to enhance significantly their performances, these layers operate at various temperatures in pulsed operating mode which drastically increases the possibility to discriminate mixtures of gases thank to appropriate data analysis. The main drawbacks of these structures concern the complexity of the process, the limit of detection above ppm and the power consumption as well.

The one-dimensional nanostructures, such as nanowires (NWs) [1] or the nanotubes [2] are very promising for new generations of sensors with very low power consumption needed and potential sub-ppm detection. This is due to their very high form factor (surface / volume ratio), but also by the ability to be functionalized. The silicon NWs, popularized by Lieber [3], are particularly attractive due to their high sensitivity, biocompatibility and diversity of possible applications (gas [4] chemicals [5] biological [6] sensors).

There are two main approaches to structure NWs: a "bottom-up" approach (rising) and "top-down" (down) [7]. The first method involves the growth of NWs by synthesis from elementary constituents by chemical reaction (polymerization) or physico-chemical assembly (crystal growth). The main limitation of this approach is the integration of NWs obtained in devices, due to difficulties in positioning the one hand, and to contact them electrically on the other hand. In the case of the "top-down" approach, the nanowire is formed by masking and then etching of bulk material. The key point of this method is the solution of nano-masking patterns, which often requires expensive equipment (electron beam lithography).

NWs based gas sensors have already been discussed in the literature and various materials have been studied, such as SnO_2 [8], CuO [9], Si [10] and InAs [11]. Whenever in a configuration known as "resistor", which consists in measuring the variation of electrical resistance of NW induced by variation of surround atmosphere. Currently, the best performance for a gas sensor based on silicon NWs (without any functionalization), from the viewpoint of the detection NH_3 and NO_2 was obtained by using horizontal NWs with a diameter of 130 nm [10]. The detection limit is closed to 0.5 ppm, and the sensitivity around 27%. The InAs NWs also demonstrate good sensitivity to NO_2 (at 115 ppb), but with a relatively long response time (10 min) [11].

The objective of our present studies is to develop a new generation of highly sensitive gas sensors based on nanostructuring silicon as vertical nanowires well controlled with reproducible manner by a "top-down" approach. These nanowires are electrically contacted by a metallic suspended bridge. Thus a large surface NWs is available, and can react with the surrounding gas. This approach allows networks of NWs defined by optical photolithography. The number, diameter, spacing and position of NWs are perfectly controlled and thus we obtain reproducible devices. The sensors were then electrically characterized and mounted to be tested under different gas atmospheres (CO, NH_3 and NO_2).

The first best results showed a strong sensitivity to low concentration of NO_2 (30% at 50 ppb) with very low limit of detection (few ppb) and low sensitivity to both other gases.

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