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Effect of varying gate distance on the threshold voltage shift in carbon nanotube field effect transistor gas sensors

S. Eberle[a], C. Roman[a], C. Hierold[a]

[a] Micro- & Nanosystems, D-MAVT, ETH Zürich, Zürich, 8092, Switzerland
e-mail: seeberle@micro.mavt.ethz.ch

Abstract

Suspended individual carbon nanotubes show great promise in use as gas sensors, as they are not only highly sensitive and selective, but can be operated at a few µW of power consumption. This work reports on a novel architecture and process flow to reduce the voltage range needed for a full sensor characterization to the values given by modern technology. The developed fast and flexible fabrication run yields CNTFET devices with varying gate distances, improving gate coupling up to 25 times to previous own studies. Devices with long gate distances (d_g=1.84µm) show a 3.2-times improved signal to noise ratio (voltage shift upon gas adsorption over signal variation) when compared to short gate distance devices (d_g=0.24µm).

Keywords

carbon nanotubes, gas sensors, fabrication, gate coupling, threshold voltage shift

1. Introduction

To reliably detect gas concentrations relevant for human health[1–3], as low as 40ppb for NO_2 exposure as an average annual limit[4], sensors need to be highly selective and must have low enough minimum detectable signals. Furthermore to alert overexposed individuals, short response and recovery times below one minute are necessary. Finally, to enable the use in autonomous sensor nodes and air monitoring systems the operation in ambient conditions and at ultra-low power budget become key requirements.

In order to fulfill all these requirements, research groups have explored both novel materials and miniaturization. Silicon nanowires [5,6] have been used as sensing elements, achieving detection limits down to 10ppb in the presence of humidity. In dry conditions the limit of detection is several orders of magnitude higher and observed hysteresis hinders reliable sensor calibration.

Metal oxide based sensors, either as nanoparticle films[7,8] or nanowires [9,10], show great promise in terms of response and recovery times. However, their cross-sensitivity towards other analytes, especially humidity, is not desired in most applications. Furthermore the required high operating temperature substantially increases the power consumption in most of these sensors.

Carbon based nanostructures, such as graphene [11,12] and carbon nanotubes [13], show high sensitivity towards NO_2. When building CNT sensors with a suspended channel [14], hysteresis and drift [15] as well as the power consumption [16] can be significantly reduced. An additional benefit of eliminating charge traps, when moving away from the oxide to a suspended architecture, is the reduction of flicker noise, which leads to an increase in the signal to noise ratio [17]. With the dry transfer process [14] the CNT as the sensing element is without significant chemical or other process residues and a reduction of cross sensitivity to humidity [18] can be observed.

Nevertheless, the required voltage range to perform a full gate sweep and acquire a complete transistor characteristic spans a range of several tens of volts [15–17]. This large voltage range however is not compatible with ultra-low power bias and read-out circuits[19–23] and would render the ultra-low power argument for these materials void. Therefore, this study presents a novel sensor architecture and