MEMS / Nanotechnology Integration

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A new generation of sensors is emerging based on the combination/integration of MEMS and nanotechnology. New capabilities include higher sensitivity, lighter weight, and lower power consumption. After a brief introduction into micromachining, the lecture will discuss three examples of micro/nano level gas sensors. For a different application, the lecture will also discuss the use of MEMS for bio/nano space exploration, specifically for molecular level cell identification.

The first example is the use of nanoparticles for conventional tin-oxide gas sensors (Ref. 1). To improve the long-term stability of gas sensors, MicroChemical Systems (MiCS) is manufacturing silicon micromachined gas sensors that combine silicon microstructures with nanomaterials. MiCS deposits precise amounts of nanoparticle metal oxide material as the sensitive layer on a micro-hotplate. Due to the very small grain size, such sensors have high stability and sensitivity. Key elements of the sensor include a sensitive metal oxide layer whose resistance/conductivity changes upon exposure to the gas of interest, a heater that keeps the sensitive layer at a specific temperature, and a thin dielectric membrane with low power consumption. These novel sensors avoid drawbacks of conventional tin/metal oxide semiconductor gas sensors that include compromised selectivity and long-term drift, and temperature/humidity dependence.

Forschungszentrum Karlsruhe (Ref. 2) has developed a compact electronic nose (KAMINA – KArlsruhe MIcroNOse) based on a highly integrated gradient microarray chip. All segments respond to nearly all gases (except rare gases or nitrogen) with a gradually different sensitivity, even at concentration of less than 1 ppm. The heart of the KAMINA device is a chip consisting of several gradually different gas sensors. The chip carries only one single metal oxide film (tin dioxide or tungsten trioxide) with its electric conductivity at higher temperatures (about 300C for tin oxide) sensitively and reversibly depending on the composition of the ambient gas. The chip is fabricated by partitioning the oxide film with parallel electrode strips, to form an array of individual gas sensor segments. These segments differentiate their sensitivity spectrum by both varying temperature (through individual heating elements) and varying thickness (between 2 and 20 nm) of a gas permeable membrane coating on the oxide layer. The electronic nose can be trained for a variety of applications, to identify chemical fingerprints of processes by detecting a wide range of gases, such as CO, NO_2, NH_3, H_2S, organic gases, other.

For the third gas sensor example, single walled carbon nanotubes (SWNTs) and metal oxides nanobelts or nanowires are used by NASA Ames on a pair of micromachined interdigitated electrodes (IDE) (Ref. 3). The nanotube based sensing material changes its conductivity with exposure to a variety of organic and inorganic gases & vapors. Great selectivity can be achieved by loading the nanotubes with catalytic metal, nano clusters and coating polymers. The electronic molecular sensing of the nanotubes can be understood by electronic modulation of the nanostructured devices and analytes in terms of charge transfer mechanism.

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Carbon nanotube-based chemical sensors have the following properties and advantages compared to current systems: (1) high sensitivity with potentially single molecule sensitivity due to large surface to volume ratio (SWNTs have all the atoms on the surface that are exposed to the environment), (2) fast response due to the one-dimensional quantum wire nature that makes its electronic properties very sensitive to gas absorption, (3) lower power consumption (at least 100 times less than current systems), because of a low surface energy barrier and a much lower operation temperature of around 150C compared to 500C for conventional metal oxide sensors, and (4) high thermal and mechanical stability because of a single crystalline structure and well organized molecular structure. NASA Ames is currently developing a sensor module that has a sensor chip containing 32 sensing channels using different nanostructurered materials, a complete electronic system for sensing signal acquisition, and a pneumatic pathway for gas sample delivery.

The use of MEMS technology for exploring the bio/nano space has resulted in ultra-sensitive molecular detection at much reduced weight and footprint for health monitoring and bio warfare agent surveillance. The lecture describes two devices, developed at the Institute for Cell Mimetic Space Exploration (CMISE)/UCLA (Ref. 4).

For rapid biological agent detection a reusable DNA sensor array has been fabricated on a silicon chip. The DNA-based probes target the DNA sequence of the analyte instead of indirect probing using antibodies. The sensitivity is greatly enhanced by combining the hybridization event with a signal enzyme, which activates chemical reaction and glowing of a tag to be analyzed by a computer. Even without making copies of DNA for analysis, as low as 1 E. coli cell can be detected using this sensor array. At the beginning of the development 1 million cells were required. The E. coli sample is prepared on a MEMS lab-on-a-chip, with cell lysis, peristaltic pump, and micro valve.

Another example for exploring the bio/nano space with MEMS is the electrokinetic molecular focusing technique that significantly enhances the detection efficiency for confocal laser induced fluorescence based molecular sensing. Electrodes in a micro channel concentrate fluorescence labeled molecules in a tiny probe region. The generated electric field is able to focus flowing DNA molecules to a width as narrow as 3 microns in a 120 microns wide channel with a probe volume of only 28 femto liter. This new technique reaches one molecule and one base pair mutation level.

REFERENCES:

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