

ZnO nanowires-based micro-sensor for wall pressure measurement in hydrodynamical flow

A. Serrure¹, M. Manrique Reyes², M. Abolhassan Araghi³, L. Simonet^{1,4}, L. Gimeno⁴, V. Consonni⁵, B. Salem², S. Hoerner³, G. Ardila¹, C. Ghouila-Houri¹.

¹ Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, Grenoble INP, CROMA, F-38000 Grenoble, France

² Univ. Grenoble Alpes, CNRS, CEA/LETI Minatoc, Grenoble INP, LTM, F-38000 Grenoble, France

³ Univ. Grenoble Alpes, CNRS, Grenoble INP, LEGI, F-38000 Grenoble, France

⁴ Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, F-38000 Grenoble, France

⁵ Univ. Grenoble Alpes, CNRS, Grenoble INP, LMGP, F-38000 Grenoble, France

agnes.serrure@grenoble-inp.fr

Summary:

Nanowires-based technology using zinc oxide (ZnO) has been widely investigated in recent years, for its combination of semiconducting and piezoelectric properties. Here, we designed a wall pressure sensor made of vertical ZnO nanowires (NWs) embedded in a polymer matrix, for measurements in hydrodynamical flow. Finite element analysis have been performed, demonstrating the sensor sensitivity to pressure fluctuations. Depending on the nanowires height, the sensitivity can theoretically achieve up to 1.3mV/kPa. The sensor will be wall-mounted in a water tunnel for flow characterization.

Keywords: ZnO nanowires, piezoelectric sensors, wall pressure sensors, active flow control, hydrodynamical flow sensor.

Background

In hydrodynamics, understanding and controlling wall-bounded flows could improve lifespan and performance of hydrokinetic turbines [1]. To achieve this goal, miniaturized and watertight wall pressure sensors are required.

Meanwhile, ZnO thin films, both piezoelectric and semiconducting, have been studied for energy harvesting and sensing applications as an alternative to toxic, non-renewable materials like PZT [2]. In the past twenty years, ZnO NWs, enhancing piezoelectric properties, have also been developed with low-cost fabrication processes and encouraging results for sensing [3].

Our collaborative work focuses on providing a miniaturized sensor device based on ZnO NWs to supply system feedback in a closed loop flow control experiments with an actuated hydrodynamic profile [1].

Sensor fabrication

The sensitive part of the sensor exploits piezoelectric ZnO NWs to measure the wall pressure fluctuations. The fabrication process starts with the deposition of an 80 nm-thick ZnO seed layer, on which nanowires are grown by chemical bath deposition [4]. The NWs are typically 1 μm to 10 μm high, and 40 nm in radius. They are then

encapsulated with Parylene-C, a polymer with relevant mechanical and electrical insulation properties [5].

For impedance and piezoelectric response to flow pressure measurements, ZnO NWs must be sandwiched between electrodes. The low-resistivity Si substrate and a 50 nm/150 nm-thick sputtered gold (Cr/Au) layer play the role of bottom and top electrodes respectively. The sensor design can be appreciated on Fig. 1, and a SEM image of one of the devices, realized with 1 μm high nanowires, can be seen on Fig. 2.

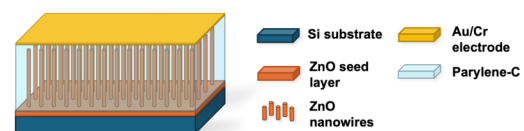


Fig. 1. Wall pressure sensor architecture.

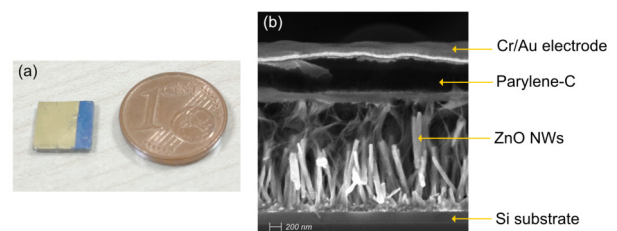


Fig. 2. Cross-sectional SEM image of the wall pressure sensor, with ZnO nanowires 1 μm high.

Simulation results

Finite element analysis (FEA) simulations have been performed using COMSOL Multiphysics software. The model includes ZnO coupled piezoelectric and semiconductor properties.

The presented simulation is based on a single-cell 3D model (Fig. 3). In the zoomed window, the square section shows a quarter of a nanowire in each corner, and the inner gap, filled with the Parylene-C encapsulation. The top electrode is metallic and the bottom one semiconductor, so as to remain as close as possible to the real device. Periodic conditions are applied to the sidewalls of the cell, to model a forest of nanowires in x and y directions.

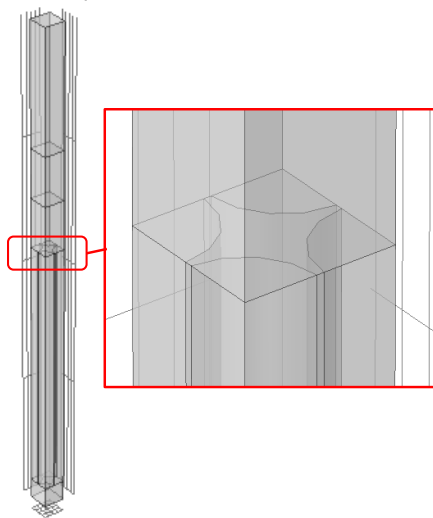


Fig. 3. Single-cell model designed in COMSOL simulation.

Wall pressure is applied on top, with values ranging from -10kPa to 10kPa, corresponding to typical experimental values of wall pressure for flows under 10 m/s in a water tunnel. Zero potential is imposed to the bottom electrode.

Fig. 4 presents the simulation results, showing the electrical voltage variation at the top electrode, for three different nanowires heights: 1 μm , 5 μm and 10 μm , corresponding to achievable nanowires heights.

The sensor exhibits a linear behavior with a theoretical sensitivity of 0.133 mV/kPa, 0.642mV/kPa and 1.28mV/kPa for nanowires of respectively 1 μm , 5 μm and 10 μm high. For extreme simulated values of wall pressure, the measured electric potential is in the order a few mV. These values are compatible with commercially available electronics (high precision signal conditioners and instrumentation amplifiers), simplifying future work on sensor interfacing.

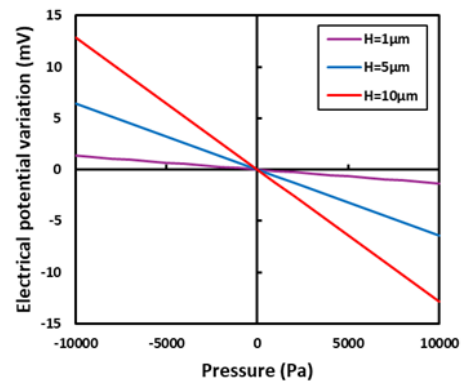


Fig. 4. Electric potential variation measured in top electrode simulation, for $P=[-10\text{kPa}, 10\text{kPa}]$ and for $H=\{1\mu\text{m}, 5\mu\text{m}, 10\mu\text{m}\}$.

Outlook

In the near future, the sensor will be integrated and made watertight to allow wall-mounting. Finally, the sensor will be characterized electromechanically then tested in a hydrodynamic tunnel, with flow velocities varying from 2m/s to 10m/s. These results, as well as further numerical investigations, will be presented at the conference.

Acknowledgements

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