# Zinc oxide nanowires-based flexible force sensor

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Human-oriented technologies (i.e., electronic and robotic skins, prosthetics, surgical robotic arms and rehabilitative devices, force-sensitive buttons on smartphones)[1] are becoming ubiquitous and part of daily life, therefore the requirement for improved force sensors is self-evident[2, 3]. Current flexible force sensors need a transformative approach to design and fabrication in order to enhance functionality and overcome drawbacks such as integrability and limited wearability (flexible but not stretchable) and satisfy requirements such as near zero-power consumption and large force and spatial resolution. We are developing a flexible device that combines piezoelectric and resistive transductions to enable static and dynamic force measurements using a single sensor and to maximize force resolution. The device features piezoelectric nanowires[4] embedded into flexible polymer materials.

Figure 1 shows a schematic of the fabrication process flow. A 3 cm x 3 cm Kapton film (125 µm thick) is secured on a silicon (Si) chip. Afterwards, an aluminum (Al) electrode layer (500 nm thick) and a zinc oxide (ZnO) seed layer (100 nm thick) is deposited on top. The seed layer is masked with photoresist to expose a circle with a diameter of 1 cm. ZnO nanowires are synthesized hydrothermally using zinc nitrate hexahydrate and hexamethylenetetramine[5]. The photoresist is removed defining the nanowires into a circular pattern. Polydimethylsiloxane (PDMS) (8 µm thick) is spin coated followed by sputtering of a top Al electrode. The Si chip is removed and the Kapton substrate with the integrated nanowires is encased in PDMS. A test device (Figure 2) has been fabricated on a Si chip to validate the fabrication steps. A complete device, fabricated on a Kapton substrate and encased in PDMS, is shown in Figure 3. The test device has been characterized by applying a compressive force using a motorized test stand. A voltage of 2 V has been applied between the top and bottom electrodes and the electric current has been measured when applying the force (Figure 4). The largest response occurs for applied forces of 4 N and 5 N. In addition, the completed flexible device has been subjected to the bending seen in Figure 3 while connected to a voltmeter and a voltage of 13 mV has been measured.

In this paper, we will present the detailed fabrication process and the measurement results obtained from the fabricated flexible force sensors. In particular, we will investigate the voltage output as function of applied force. We will discuss the device operation mechanism and force sensitivity.

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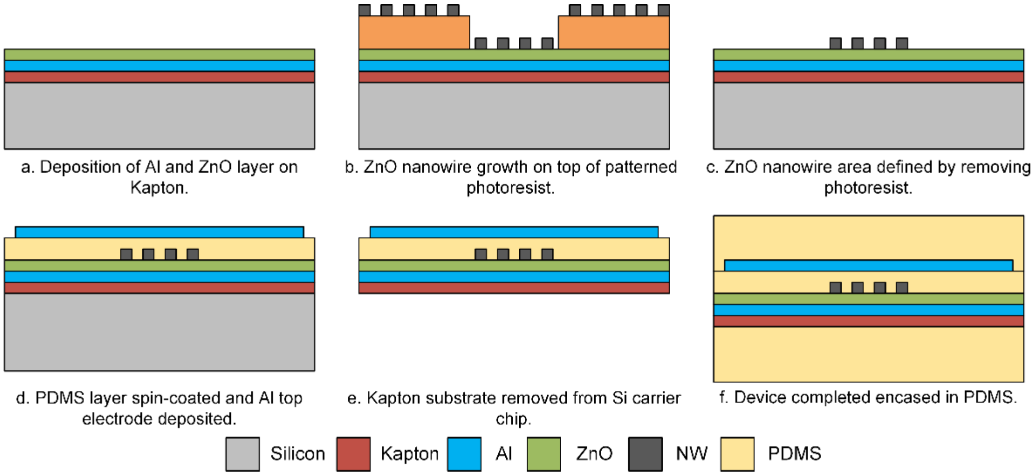
a. Deposition of Al and ZnO layer on Kapton.

b. ZnO nanowire growth on top of patterned photoresist.

c. ZnO nanowire area defined by removing photoresist.

d. PDMS layer spin-coated and Al top electrode deposited.

e. Kapton substrate removed from Si carrier chip.

f. Device completed encased in PDMS.

*Figure 1:* Fabrication process flow for a flexible force sensor.

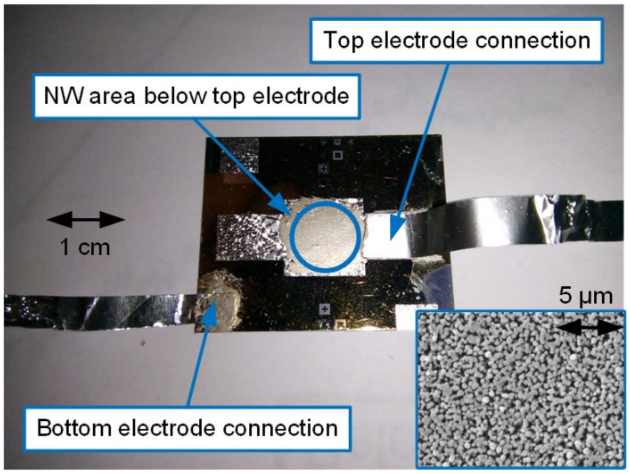

*Figure 2:* Force sensor fabricated on Si substrate. Inset: SEM image of nanowires.

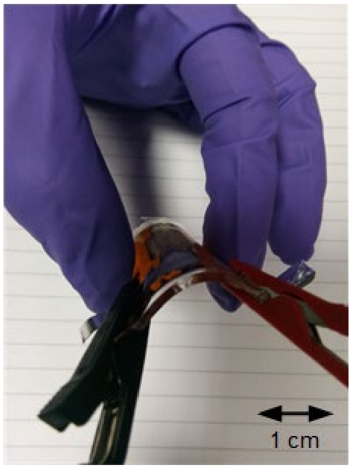

*Figure 3:* Bending test on device fabricated on Kapton substrate.

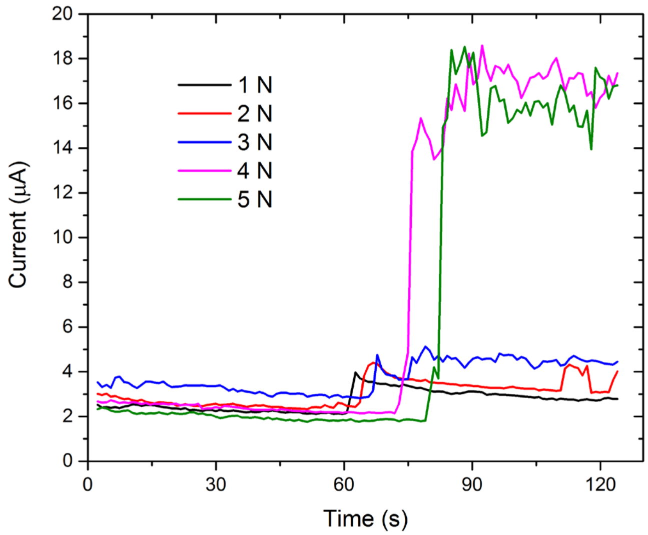

*Figure 4:* Measured current output from device for compressive forces up to 5 N.