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Design of a Silicon Beam Resonator for a Novel Gas Sensor

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Abstract: A new silicon beam resonator design for a novel gas sensor based on simultaneous conductivity and mass change measurement is investigated. High selectivity and sensitivity in gas detection can be obtained by measuring the charge-to-mass ratio of gas molecules. Structures of silicon beam resonators are designed, simulated, and optimized. This gas sensor is fabricated using sacrificial layer microelectronmechanical system technology, and the resonant frequency of the microbeam is measured.

Key words: MEMS; micro gas sensor; charge-to-mass ratio; sacrificial layer technology
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1 Introduction

Micro gas sensors have potential in a wide variety of chemical vapor detection applications[1~4]. Numerous studies have been aimed at improving the selectivity of chemical micro sensors since poor selectivity and recognition of sensors are serious drawbacks. Traditional sensors detect gases by measuring resonator conductance[1~3] or frequency[4]. According to the principle that an atom can be identified by its charge-to-mass ratio[5], we propose that a high selectivity in gas detection can be achieved by measuring the charge-to-mass ratio of gas molecules. Accordingly, we design a sensor that can simultaneously measure both the charge and mass of gas molecules. After a gas is absorbed in the gas-sensitive film, the molecules' charge and mass are obtained by measuring the conductivity change of the gas-sensitive film and frequency shift of the resonator.

In this paper, we present the design of a silicon beam for the gas sensor resonator. This structure offers high sensitivity, accuracy, resolution, and stability. Because it is based on IC technology, there is good potential for reducing transducer dimensions and adding on-chip circuitry. The vertical and horizontal structures of this silicon beam are designed and fabricated through sacrificial layer microelectronic system (MEMS) technology. Experimental results demonstrate that the silicon beams with this structure perform well and are suitable for gas sensing applications.

2 Design

The structure of our micro gas sensor, based on a silicon micro bridge, is illustrated in Fig. 1. This gas sensor detects a gas by measuring the change of the resonance frequency of the beam caused by gas absorption in the gas-sensitive film on the beam. The first layer, SiO_2/Si_3N_4, is used for isolation. The second layer, poly-Si, acts as the

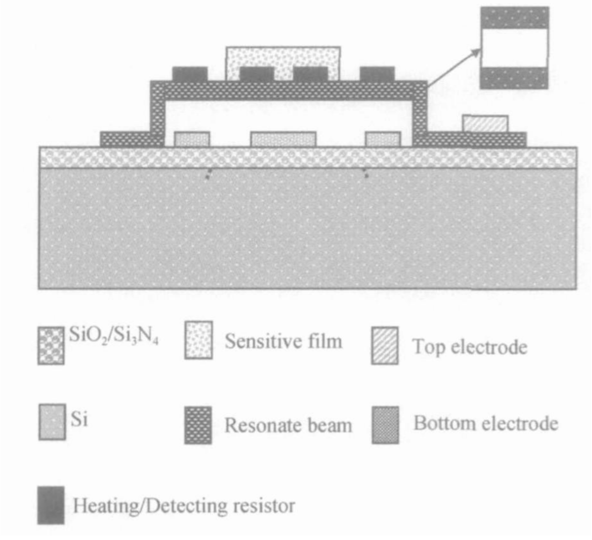

Fig.1 Schematic structure of the sensor

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bottom electrode to excite and detect vibration of the silicon beam. A 2mm thick PSG layer is used as a sacrificial layer, which is etched by HF in the last step. The resonator microstructures are double-ended and are deposited with Si_3N_4/poly-Si/Si_3N_4 in turn. The upper Si_3N_4 acts as an insulation layer between the top electrode of lead wires and the poly-Si electrode. The thicknesses of these three layers are 200, 1000, and 200nm, respectively. As shown in Fig. 2, six resonators are designed. The structures considered have three shapes: rectangle, bipod, and tripod rectangle beam; and two lengths: 350 and 500μm. On top of the Pt on the beam that acts as the lead wire of the top electrode, a 100nm heating/detecting resistor component of the sensitive film is deposited. Another 100nm of Au is deposited on the Pt as a pad. The upper-most layer is a gas-sensitive film that can absorb gas molecules.

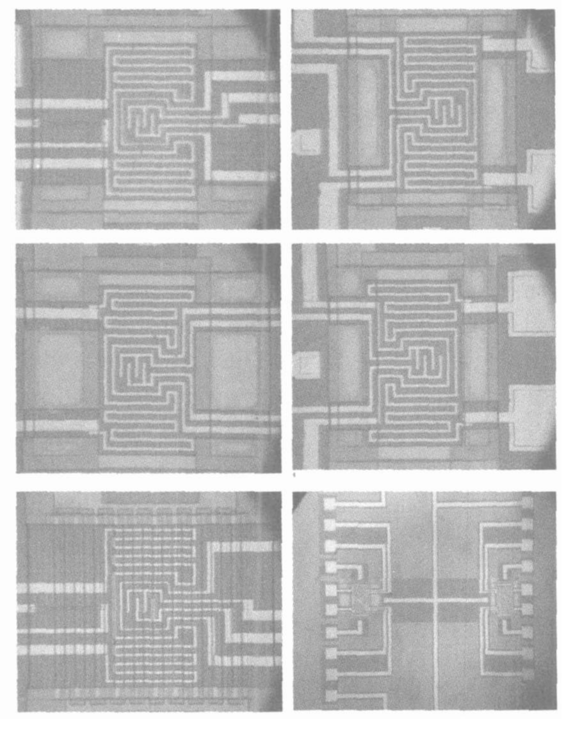


Fig. 2　Top view of a sensor chip　One device is with 6 types of resonators.

We used ANSYS 5.4, finite element analysis (FEA) software, to simulate the vibration mode of the silicon beam. The simulation results are shown in Fig. 3. At the first mode, the interface of tension stress and compressive stress in the surface of the beam is located at the spot 0.225 times the overhanging length of the beam. Based on these simulation results, we put a heater and temperature detector at the middle of the beam, and a vibration exciter and detector at the two fixed ends.

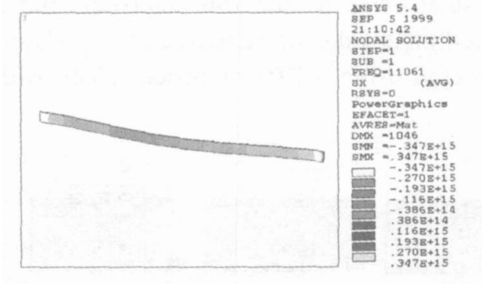


Fig. 3　Vibration mode of the beam

Since excess tensile stress on Si_3N_4 influences the properties of this micro gas sensor, we improved the mechanical properties of this film by ion implantation. Figure 4 shows the influence of ion energy and dosage.

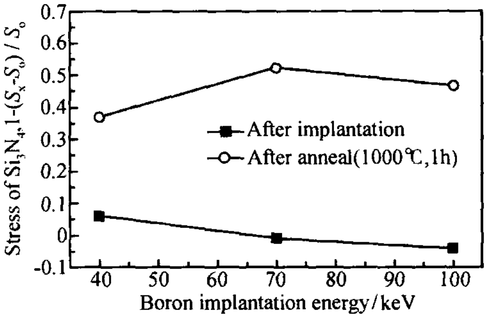


Fig. 4　Stress change versus implantation energy for Boron ions

3　Fabrication

The fabrication process is shown in Fig. 5. Double-sided polished 100mm diameter n-type (100) silicon wafers with a thickness of 400μm served as the substrate. Fabrication began with the 200nm thermal SiO_2 and the 200nm LPCVD Si_3N_4 for high boron doping. Then the bottom electrode of 400nm poly-Si and a sacrificial 2μm PSG layer were deposited using LPCVD and etched. A poly-Si side-wall was then created by reactive ion etching so that the Pt-wire would trace smoothly at the corner of the beam. Then we carried out the deposition and etching of Si_3N_4/poly-Si/Si_3N_4 in turn to form the silicon beam. After the deposition of the Si_3N_4 layer, ion implantation and annealing processes were carefully controlled based on parameters determined by stress-controlled experiments conducted before the fabrication. Because Pt resistance varies linearly with temperature, it serves both as the heater and temperature detector of the sensitive film. This layer, including the Pt lead wire of the top electrode and inter-digitated electrodes of sensitive film resistor, was constructed using a lift-off process. The width of the heating elements was 4μm and the space between heater and detector elements was 8μm. The next step in sensor fabrication was the formation of the sensitive film by machine and the release of the sacrificial layer with HF (40 %) for 7min by sublimation.

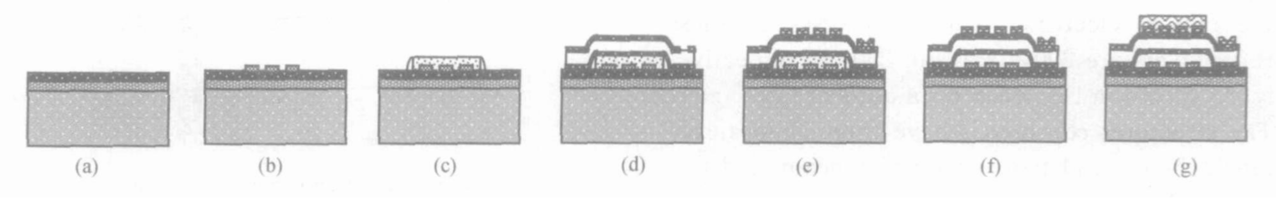
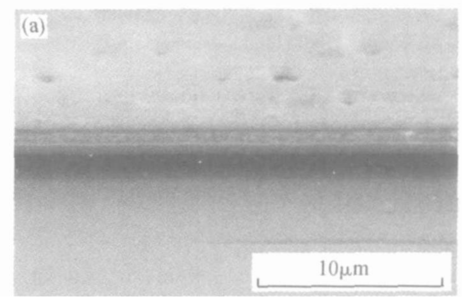


Fig. 5 Fabrication process of the gas sensor (a) Thermal SiO_2 and LPCVD Si_3N_4; (b) Depositing bottom electrode; (c) Depositing PSG and forming side-wall by RIE; (d) Depositing Si_3N_4/poly-Si/Si_3N_4 and patterning beam; (e) Sputtering and patterning Pt; (f) Release PSG with HF; (g) Depositing gas-sensitive film

4 Results and discussion

The fabrication results of the silicon beam are shown in Fig. 6. It can be seen that the stress of the beam was well controlled and that the side-wall was even enough to avoid rupturing the wire. The silicon beam was operated in an electrostatic-exciting mode using DC and AC power in series, which were connected to the top and bottom electrode, respectively. The DC power supply was 15V and the AC power amplitude was 9.8V. The AC supply frequency varied from the simulated value by - 30 % to + 30 %. The resonant frequency was measured with a laser frequency-measurement instrument using the optical path difference. The oscillagraph connected to this instrument reached its maximum when the silicon beam resonated with the AC power supply frequency. The frequency of the silicon beam measured without sensitive film was 41.6kHz, which is close to the previous simulation results.



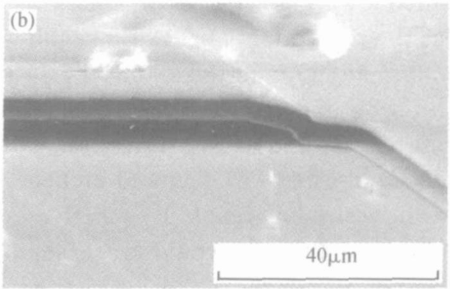


Fig. 6 SEM images of the poly-Si resonator beam
(a) After sacrificial PSG etching; (b) Clamped end aspect

The gas sensor was exposed to different concentrations of H_2O vapor. The frequency and conductance shifts of the sensitive film as functions of vapor concentrations are measured and shown in Fig. 7. The silicon beam dimensions are 300μm × 500μm. More details will be presented in future papers.

5 Conclusion

A micro gas sensor based on a silicon beam resonator is fabricated. After gas molecules are absorbed by sensitive film on the silicon beam, the frequency of the beam is reduced due to the additional mass, and at the same time the conductance of the film is changed. A silicon beam with this structure is suitable for the two-parameter gas sensor we want to achieve.

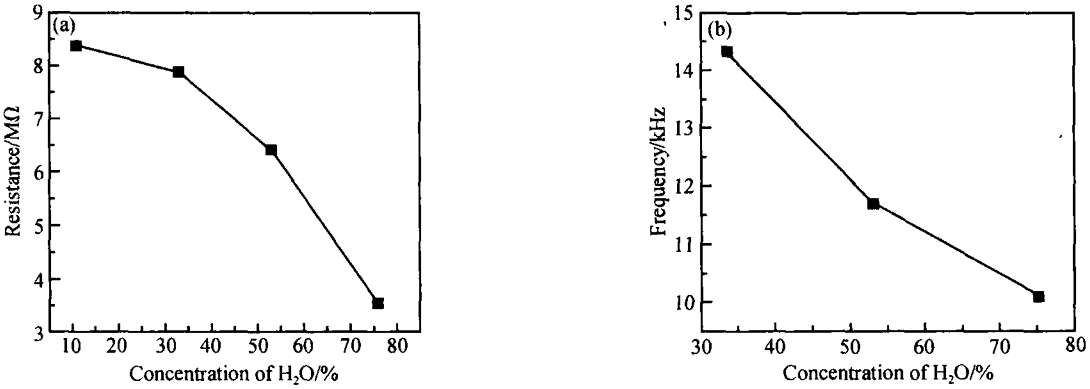


Fig. 7 Resistance and frequency change versus H_2O vapor concentration

References

[1] Sun A, Yang Y, Jiang Y, et al. Electro-mass olfactory multi sensor. Sensors and Actuators B, 2000, 66:88

[2] Tsai P P, Chen I C, Ho C J. Ultralow power carbon monoxide microsensor by micromachining techniques. Sensors and Actuators B, 2001, 76:380

[3] Zee F, Judy J W. Micromachined polymer-based chemical gas sensor array. Sensors and Actuators B, 2001, 72:120

[4] Moldovan C, Kim B H, Raible S, et al. Manufacturing of surface micromachined structures for chemical sensors. Thin Solid Films, 2001, 383:321

[5] Hwang B K, Yang J Y, Lin C W. Recognition of alcohol vapor molecules by simultaneous measurements of resistance changes on polypyrrole-based composite thin films and mass changes on a piezoelectric crystal. Sensors and Actuators B, 2001, 3707:1

基于硅悬臂梁谐振器的新型气体传感器

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摘要: 研究了一种基于硅悬臂梁谐振器的新型气体传感器. 该传感器在敏感环境中, 可同时获得敏感膜电导率和质量变化, 测量被测气体分子的荷质比, 具有高灵敏度和高选择性. 根据这一原理, 针对气体传感器的需求, 设计了硅悬臂梁谐振器化学传感器结构, 进行了仿真优化, 并采用MEMS表面牺牲层工艺制备该器件, 激光频率仪测量验证了该微型谐振梁的谐振频率.

关键词: MEMS; 气体传感器; 荷质比; 牺牲层工艺

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