

MICROSTRUCTURING OF PIEZORESISTIVE CANTILEVERS FOR GAS DETECTION AND ANALYSIS

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1. Introduction

The development of different gas sensors has been a subject of extensive research efforts in recent decades. The physical and chemical properties of the gas (temperature, pressure, density, gas flow, gas composition, etc.) are essential for all gas applications [1]. The ability to detect small amount of gases is crucial in the environmental protection (greenhouses, acid rains, destruction of the ozone layer, air pollution, etc), for the control and safety of industrial processes as well as for some military and security applications (like detection of explosive ordnances, the weapons of mass destruction and chemical warfare agents from a very small amount of trace gas species they release) [2]. The recent advances in microelectromechanical systems (MEMS) have facilitated development of sensors that involve transduction of physical quantities into convenient output signals and rely on mechanical phenomena [3]. In this work we report on a design and fabrication of cantilevers for gas detection and analysis. The cantilevers have expanded area of interaction with the gas, while the signal transduction is realized by an integrated piezoresistive deflection sensor, placed at the narrowed cantilever base with highest stress along the cantilever. Moreover, the cantilevers have integrated bimorph micro-actuator detection in a static and dynamic mode. The cantilevers are feasible as pressure, temperature and flow sensors and under chemical functionalization – for gas recognition, tracing and composition analysis.

2. Experimental

The cantilevers for gas detection are designed in AutoCAD, the fabrication technology is developed and the required set of 6 optical masks is realized by e-beam lithography using ZBA 21 electron-beam pattern generator, available at the institute of Informatics, Slovak Academy of Sciences. A high-accuracy in the reproduction of the designed dimensions is necessary in order to achieve optimal performance of the cantilever sensors. It is realized by correction of the e-beam exposure dose at the critical places, where otherwise the proximity effects lead to distortion of the exposed shape.

The fabrication sequence of the cantilevers for gas and pressure detection is presented in Figure 1. The realization starts from double sided polished n-Si wafers with orientation $\langle 100 \rangle$ (0) and specific resistivity 5-10 Ωm . The wafers are oxidized ($1\mu\text{m SiO}_2$) in water vapour atmosphere, then the oxide from the front side is etched in a buffered oxide etcher

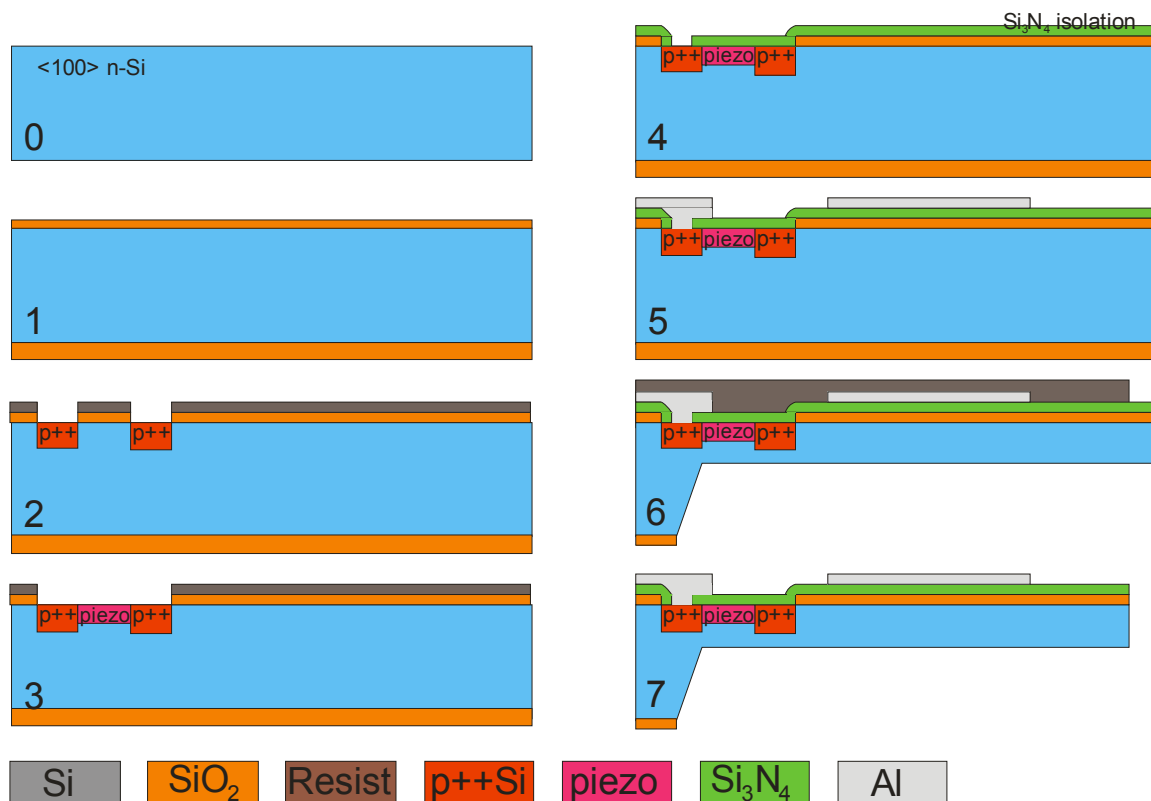


Fig.1: *Fabrication sequence for cantilevers for gas detection and analysis.*

(BOE) and the wafers are again oxidized (200 nm) in dry O₂ environment (1). This thin film oxide introduces negligible defect surface states and ensures good electrical isolation. Then areas for highly-doped p++ contact pads are lithographically defined, the SiO₂ is etched in BOE and implanted with B⁺ ions (2) using a double photo-resist-SiO₂ mask. In a similar way

the piezoresistors are patterned and the sensors are formed by appropriate middle-dose B⁺ ion implantation (3). After stripping of the resist the implanted atoms are activated by a rapid thermal annealing (RTA). Next, the surface of the wafer is passivated by 200 nm of plasma enhanced chemical vapour deposited (PECVD) Si₃N₄. This passivation film is patterned by lithography and reactive ion etching (RIE) forming contact windows to the p⁺⁺ areas (4). Further, 800 nm aluminum layer is deposited and the metallic wiring connections and micro-actuators are realized by a lithographic step and consequent wet etching of Al (5). As a next task the cantilever membrane has to be realized. A bulk-micro-machining is employed, as the thick back-side oxide is patterned by lithography and BOE etch. Afterwards the thick SiO₂ areas are used as an etch-mask for anisotropic back side silicon etched in potassium hydroxide (KOH) until the desired membrane thickness is obtained (6). After that the cantilever shape is lithographically defined using a thick photoresist and the cantilevers are etched free by a vertical RIE process [4-5]. Finally, the resist is stripped and the ready cantilevers are separated mechanically (7).

3. Results and Discussion

Cantilevers are successfully realized following the described fabrication sequence. Figure 2 presents an optical *a*) and a scanning electron microscopic (SEM) *b*) picture of the gas probes. The position and configuration of the piezoresistive bridge is clearly visible at the narrower membrane part at the bottom of the cantilever, where the stress due to the deflection is concentrated. In such a way a maximum change in the resistance is obtained by a cantilever deflection (e.g. induced pressure difference).

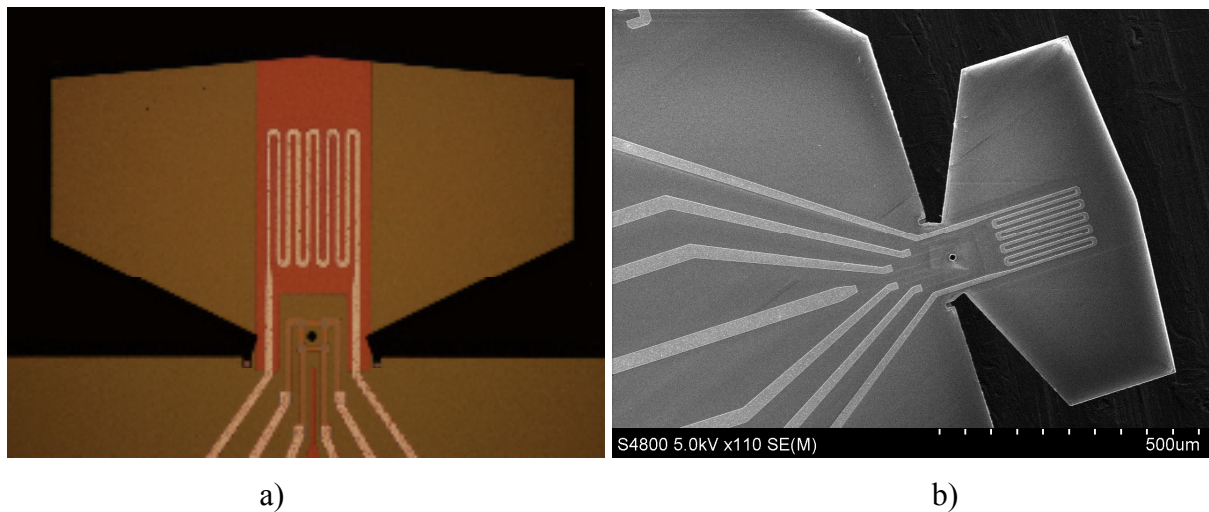


Fig. 2: Pictures of the gas-detection cantilever: *a*) optical, *b*) SEM.

The cantilevers have integrated bimorph actuator, created by two materials with much different coefficient of thermal expansion. Setting of a proper AC current through the actuator drives thermally the cantilever [5] and it oscillates at its main mechanical resonance, allowing dynamical detection. The cantilever can be fine positioned by a DC current. Figure 3 shows the oscillation spectrum of the cantilever, driven by its actuator. Figure 3a) was recorded optically by a vibrometer, while 3b) was measured electrically from the piezoresistive bridge. In both cases the main resonance at 21.7 kHz is clearly visible. The sensitivity of the piezoresistors is several m Ω /nm, which allows z-deflection of the cantilever of 1 nm to be detected.

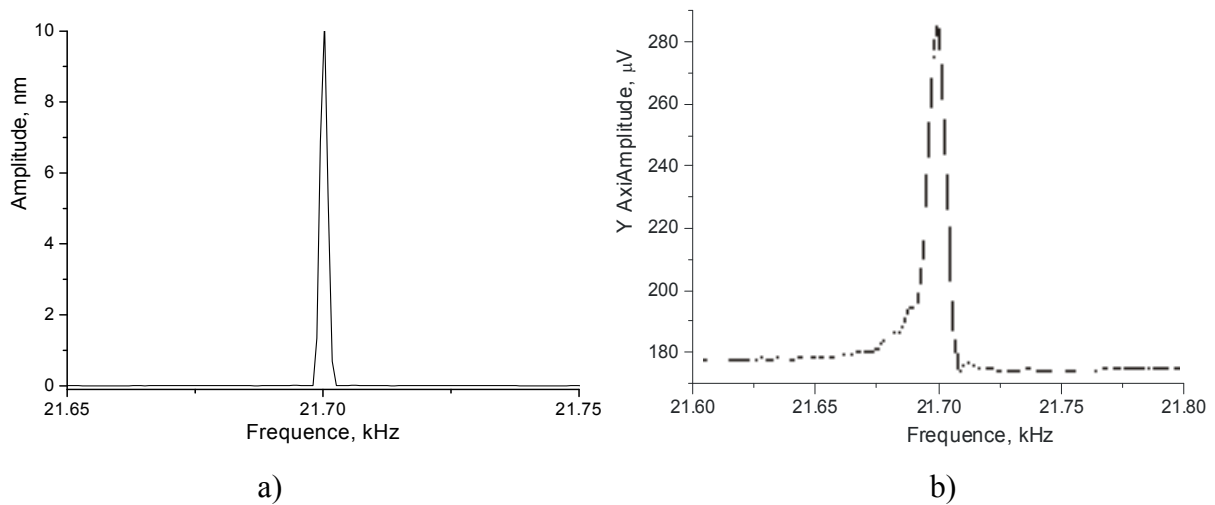


Fig. 3: *Resonance actuation of a cantilever, measured: a) optical, b) piezoresistive.*

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References:

- [1] J. Janata: Principles of Chemical Sensors, Plenum, New York (1989).
- [2] M. Saarinen: Cantilever enhanced gas sensing using photoacoustic spectroscopy, M.Sc. Thesis, Faculty of Electronics, Aalto University, Finland (2010).
- [3] N. Lavrik, M. Sepaniak, P. Datskos: *Rev. Sci. Instrum.*, **75**, 2229 (2004).
- [4] Y. Sarov et al.: *J. Vac. Sci. Technol. B*, **27**, 3132 (2009).
- [5] Y. Sarov, T. Ivanov, A. Frank, I.W. Rangelow: *Appl. Phys. A*, **102**, 61 (2011).