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Zeolite-trench-embedded micro cantilevers for CMOS strain-gauge integrated gas sensors

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Abstract

Recently, Zeolites have been expected for material of sensitive gas sensors. In this report, Zeolite-coated micro cantilevers having micro trenches have been developed. Zeolite is porous material that absorbs chemical substances. The mass increases by gas absorption, and the cantilever resonance frequency decreases accordingly. In this paper, design and a new micro cantilever with silicon micro trench for more sensitivity, integrated with CMOS-made polysilicon strain gauges instrumentation preamplifier is reported. Post-process fabrication over foundry-made CMOS chip was successful. Preliminary measurement has shown a clear shift of resonance frequency by ethanol gas.

1. Introduction

Gas sensors have been studied for personal authentication, food development, environmental measurement, health management, and so on.

We consider that integration of signal processing circuit and putting MEMS gas detectors on chip in an arrayed configuration will give advanced features and performance for gas sensors. By processing the signals from many gas detectors composed of different materials in deep learning, it is considered to be applied to applications such as micro gas chromatography, or device to react immediately when started off-flavor occurs or there are dangerous gases.

However semiconductor type gas sensor which has been most used is not sufficient performance for these applications. The problems of gas sensor are selectivity, and sensitivity. Zeolites have been proposed to improve the selectivity. Zeolite has a very high selectivity by the characteristics (Molecular sieve, Adsorption, Ion-exchange) of them. Various gas sensors using zeolite have been studied [1]. In addition, gas sensors need more sensitivity. In the field of chemical sensors, lowering of sensitivity limits has continued by development of mass sensors such as quartz crystal microbalances (QCM) and MEMS/NEMS cantilevers. The NEMS devices have a resolution at the attogram [2].

Therefore, zeolite-coated micro cantilevers have been expected high selectivity, and high sensitivity. In recent year, zeolite micro cantilevers are studied [3] [4] [5]. In addition, micro cantilevers can be coated different sensitive layer (zeolite: LTL, MFI, ZSM-5, etc.). By integrated them, it is considered that allow higher sensitive and higher selectivity gas detection [5].

In this summary, we propose new cantilever design for more improving those zeolite-coated cantilevers. Recent development of MEMS technology have realized high aspect ratio silicon micro trench by Bosch process. Zeolites are coated as a membrane until now. However, we consider 2D to 3D. Integrating zeolites into silicon micro trench give more sensitivity and Miniaturization. Therefore, we propose Zeolite-trench-embedded micro cantilever. This device was fabricated by CMOS-MEMS Integration. We successful integrate cantilever, strain-gauge, and instrumentation amplifier on chip. In a similar process, the device embedded to zeolite comb-drive actuators can give the electric characteristics of zeolites. In this way, the integration of these devices is going to give more selectivity for gas detection.

2. Experiment

Design

Fig.1 shows micro cantilever design. The cantilever has silicon micro trench, and this structure increase the area of surface and volume of zeolites as a gas detector. And the mass ratio with silicon and zeolites are higher, that has been expected more sensitivity. The cantilever with silicon micro trench vibrates by electromagnetic force. Fig.2 shows strain gauges CMOS layout. The strain-gauges are at the base of the cantilever. Fig.3 shows this device. Fig.4 shows zeolite-trench-embedded (SEM photomicrographs). Integration of zeolites into silicon micro trench is successful. It was dropped a droplet of zeolites in ethanol, and pushed.

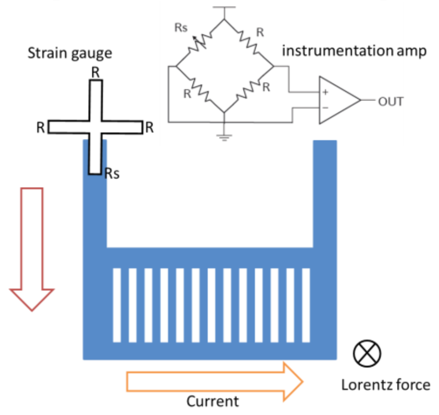

Fig.1 micro cantilever design

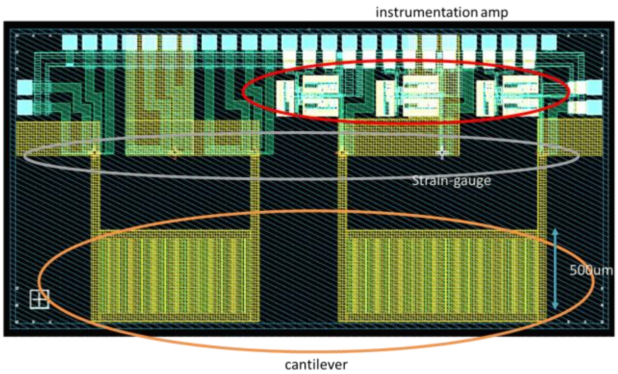

Fig.2 micro cantilever layout

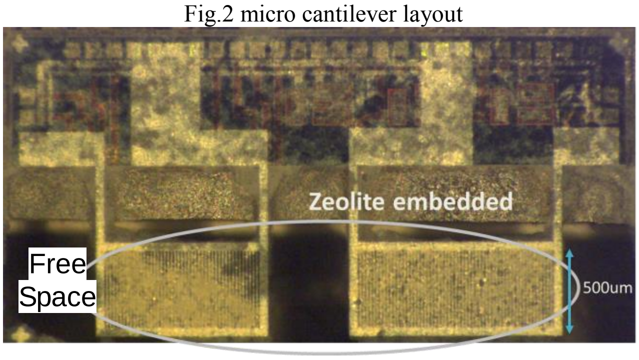

Fig.3 device photomicrograph

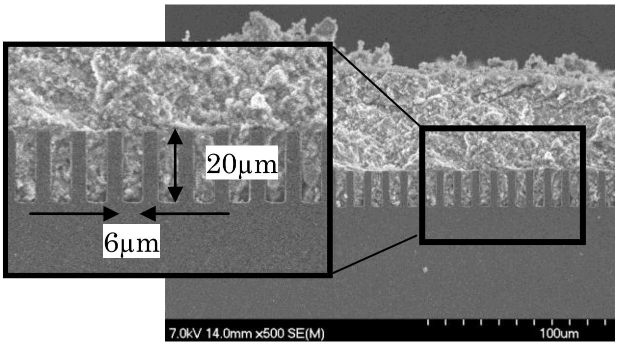

Fig.4 zeolite embedded into silicon micro trench. (SEM)

Fabrication

Fig.5 shows this process flow. Strain gauges and instrumentation amplifier were fabricated by a foundry on a SOI wafer with a CMOS process (Fig. 5(a)). Next, we fabricated cantilever. First, we sputtered aluminum on the surface (SiO_2 layer) and chip backside, and, etched extra aluminum after electron beam lithography for making wiring for the cantilever (Fig. 5(b)). Next, we sputtered SiO_2 and aluminum (Fig. 5(c)). This is hard mask for making 10um trench cantilever. Extra aluminum is etched after electron beam lithography (Fig. 5(d)). After that, we etched surface SiO2. Next, we etched Si anisotropy by Bosch process to BOX layer, and the BOX layer etched (Fig. 5(e)). We removed mask aluminum layer and SiO_2 layer (Fig. 5(f)). Next, we embedded zeolites (Cu-LTL) into micro trench as Fig.4. It was dropped a droplet of zeolites in ethanol, and pushed while warming by Flip Chip Bonder (Fig. 5(g)). After that back side Silicon are etched by Bosch process (Fig. 5(h)).

Measurement

Displacement of the cantilever was measured by laser Doppler vibrometer (MSA-500). Fig.6 shows measurement result. That shows change of resonance frequency by ethanol detection. This cantilever's resonance frequency was 25.03 kHz and changed to 25.00 kHz under ethanol.

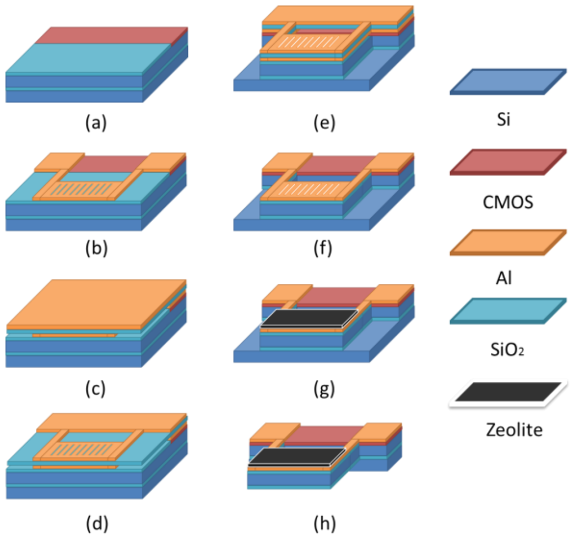

Fig.5 Fabrication

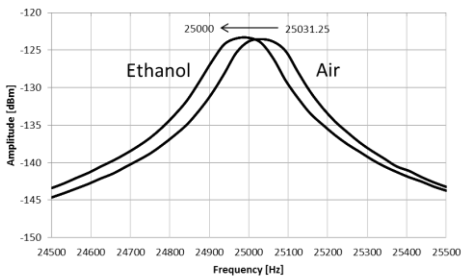

Fig. 6 change of resonance frequency

3. Conclusions

We proposed new design; Zeolite-trench-embedded micro cantilever with CMOS pre-amplification circuit. We successfully fabricated the device with integration on a CMOS chip. It can be measured change resonance frequency by ethanol gas absorption as a preliminary experiment. It was confirmed behavior of the cantilever.

References

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