Ultra-miniaturized monolithically integrated polymer coated Si optoelectronic cantilevers for gas sensing applications

Misiakos K, Raptis I, Goustouridis D, Gerardino A[+], Contopanagos H, Valamontes E[++], Kitsara M
Institute of Microelectronics, NCSR 'Demokritos', 15310 Athens Greece, misiakos@imel.demokritos.gr
[+] Istituto di Fotonica e Nanotecnologie (IFN), CNR, 00156 Roma, Italy
[++] Electronics Eng. Dept, TEI of Athens, 12243, Athens Greece

Summary

The cantilever based devices relying on optical beam steering, even though sensitive as sensors, have rather limited penetration to the market. The obstacle that has prevented so far the wider spread of such devices is the inability to monolithically integrate the photonic components on the same die with the cantilever. In this work for first time, to our knowledge, a microsystem is presented comprising integrated Si light sources and detectors self aligned to suspended Si_3N_4 cantilevers, acting as waveguides, all monolithically integrated in the same Si chip through standard microelectronics processing. The cantilever is coated with a polymeric film that selectively absorbs analyte molecules from the environment causing a change in the film stress and commensurate cantilever's deflection which is monitored as change in the photocurrent. The PMMA coated device showed detection of VOCs, in a wide concentration range from few tens of ppm, limited only by the physicochemical properties and the chemical affinity of the polymer used.

Motivation

Microcantilevers based on optical detection principle are more sensitive from their electrical counterparts based on piezoresistive/piezoelectrical or capacitive approaches. Even though optical microcantilevers have achieved very high sensitivities in both chemical and biological case studies their use in real applications is limited mainly due to need of off-chip optics to illuminate the cantilever and collect the reflected light. The present work overcomes this barrier with the introduction of a truly integrated optoelectronic transducer[1] where all optical components i.e. light source, photodetector and cantilever, acting as waveguide, are coupled and integrated on the same Si chip (Fig. 1).

Results

In Fig. 2 a tilted side-view SEM image of a defected cantilever device having completely released as well as unreleased fingers is illustrated. By using the unreleased fingers as a reference the cantilever edge deflection is measured 494nm. An independent method for deflection monitoring through mechanically enforced bending is shown in fig. 3. A 50μm thick SU-8 pad patterned on a Si wafer was mounted on the tip of a micromanipulator needle and was aligned under a microscope and was lowered until contact was achieved between the pad and the cantilevers. Then, the motorized chuck of the prober was lowered at the lowest possible speed while the photocurrent was monitored. When separation starts, the photocurrent drops rapidly from its highest value under contact conditions to the value determined by the ambient temperature and humidity. This is another proof that the free cantilevers bend upwards where the optical coupling efficiency is smaller compared to the horizontal position. The dynamic response of the monolithic optoelectronic cantilever in a wide range of ethanol concentrations is shown in fig. 4. Clearly the response depends strongly on the concentration and in particular cases the time period was not enough to reach equilibrium due to the chemical affinity of PMMA with ethanol and ethanol's molecule size. At certain ethanol concentration (point 11) the cantilever passes through horizontal position and bends downwards. The ethanol sensitivity plot expressed as the photocurrent normalized to its maximum value (flat cantilevers) is shown in fig. 5. These plots clearly show the applicability of the polymer coated integrated optoelectronic cantilevers for gas sensing applications at a very high concentration range.

[1] E. Mavrogiannopoulou, P. S. Petrou, S. E. Kakabakos, K. "Real-time detection of BRCA1 gene mutations using a monolithic silicon optocoupler array", Biosesns. Biolelecron. vol. 24, nr. 5, p. 1341-1347, 2009

Figures

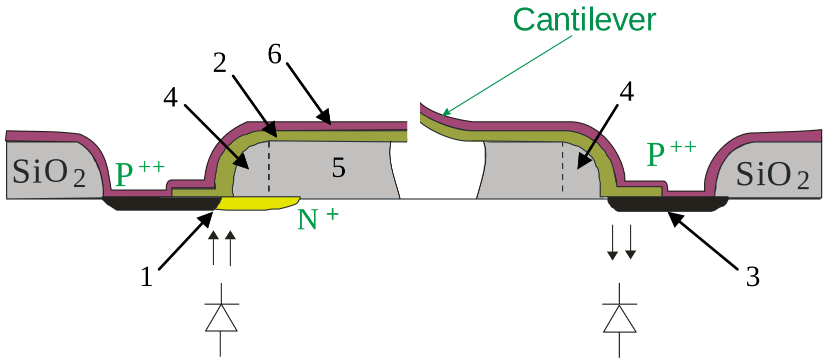
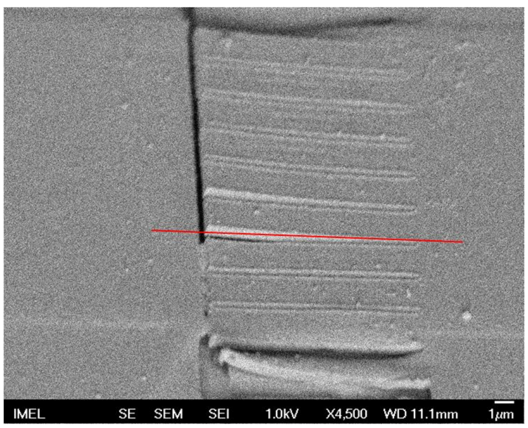


Fig. 1: Monolithic optocoupler and cantilever schematic. Light emitting diodes (1) and detectors (3) are optically linked through a self-aligned silicon nitride layer (2) while SiO_2 spacers (4) provide for the smooth waveguide bending. The cantilever was released in a BHF solution, which selectively removed the thick SiO_2 field oxide (5), following e-beam lithography patterning of PMMA (6) and reactive ion etching removal of nitride layer.



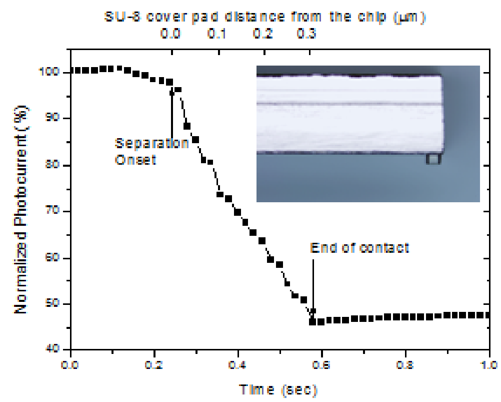
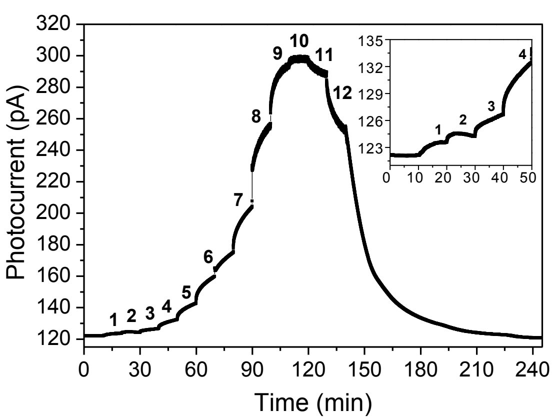


Fig. 2: SEM image showing the bended upwards cantilevers. The two fingers at the bottom have not been released, while the top six fingers are released and bent. The red line shows the reference of the unreleased fingers.

Fig. 3: Optical image of the SU-8 capping pad facing down. Normalized photocurrent vs. time during the separation of the SU-8 pad from the contact position. The upper horizontal axis indicates separation – upward deflection.



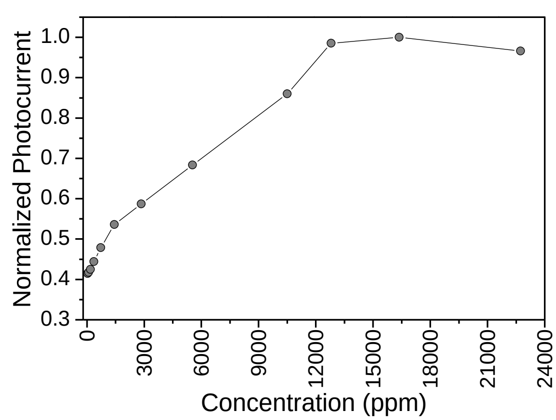


Fig. 4: Time response to ethanol vapor concentration values (in ppm) 1) 44.72, 2) 89.39, 3) 182.7, 4) 364.7, 5) 726.78, 6) 1443.5, 7) 2847, 8) 5537.5, 9) 10502.5, 10) 12798, 11) 16377, 12) 22734.

Fig. 5: Ethanol sensitivity plot expressed as the photocurrent normalized to its maximum value (flat cantilevers). In step 10 the cantilever is horizontal and in 11 bends to negative deflection.