Microcantilevers as a Platform for the Detection of Hydrogen

Gino Putrino, Adrian Keating, Mariusz Martyniuk, Lorenzo Faraone, John Dell

***Abstract*—The nanomechanical movements of microcantilevers are a unique tool for the detection of various chemicals. When a microcantilever is functionalized with a surface which specifically adsorbs the chemical of interest, the resulting surface stress will bend the microcantilever. The measurement of this bending can provide an accurate measure of the concentration of the chemical of interest. Here we consider the use of microcantilevers to detect hydrogen under ambient atmospheric conditions. We find that nanomechanical movements of a palladium/silicon nitride cantilever tip correspond to sub-milliTorr changes in the partial pressure of hydrogen in air.**

***Index Terms*—Hydrogen Sensing, MEMS, Microcantilever Sensors**

I. Introduction

Robust, stable and accurate hydrogen sensors are required for many applications including the synthesis of ammonia and methanol, the hydration of hydrocarbons, the desulphurization of petroleum products and the production of rocket fuels, nuclear reactors, and coal mine safety [1], [2]. Microcantilever sensors have the ability to measure mass with zepto-gram ($10^{-}21$ g) sensitivity [3]. These sensors are created by fabricating a microcantilever, coating it in a functionalization layer, and then watching for a detection event. When the substance being sensed bonds to the functionalization layer of a cantilever beam, the surface stresses created will cause the beam to bend. Palladium absorbs hydrogen at room temperature and exhibits a volume expansion when it does so [4], which makes it a prime candidate for use as a functionalization layer for a microcantilever hydrogen sensing system. In this work we investigate the use of microcantilevers to detect hydrogen.

II. Theoretical Analysis

When palladium absorbs hydrogen, the crystal lattice of the palladium expands resulting in a lattice distortion. For a silicon nitride cantilever functionalized with a top surface of palladium, an expression for the change in radius of curvature, R, when the palladium is exposed to hydrogen can be derived to be [5]:

$$\frac{1}{R} = \frac{2\left(\Delta V/V_o\right)a_1 E_1}{K a_2^2 E_2}\sqrt{pH_2} \tag{1}$$

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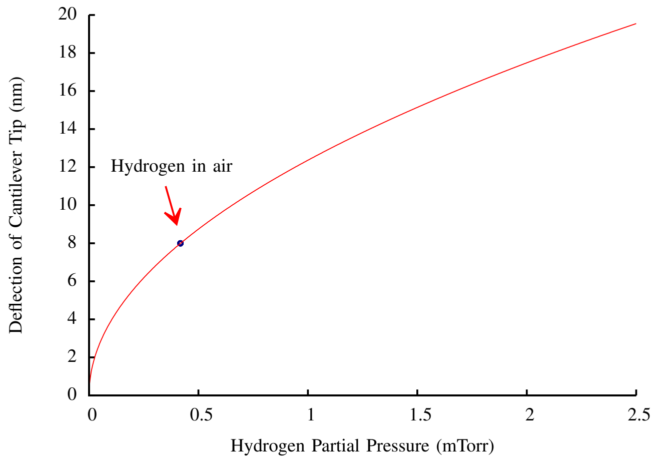

Fig. 1. Deflection at the tip of a 50 μm long Pd/SiN$_x$ cantilever due to hydrogen absorption as predicted by Equation II. The deflection due to hydrogen partial pressure in air is indicated.

where pH_2 is the partial pressure of hydrogen in Torr, V_o is the atomic volume of palladium, and ΔV is the characteristic volume change per hydrogen atom. The ratio $\Delta V/V_o$ is 0.19 [6]. The thicknesses of the palladium layer and the structural layer of the cantilever are a_1 and a_2 respectively. The Young's modulus of the palladium layer and the structural layer are E_1 and E_2 respectively. K is Sieverts's constant for the prediction of solubility of gases in metals [7]. For the case of hydrogen dissolving into palladium, $K = 49$ [5]. Equation II is only a valid approximation for hydrogen partial pressures less than 30 Torr.

Fig. II shows the deflection of a cantilever tip due to the absorption of hydrogen for a 50 μm long, 1 μ thick silicon nitride cantilever with Young's modulus of 150 GPa, coated with a 50 nm layer of palladium (Young's modulus 121 GPa [5]). It can be clearly seen that nanomechanical deflections of the cantilever tip will correspond to sub-milliTorr measurements of the hydrogen partial pressure.

III. Fabrication and Measurement Method

Microcantilevers suitable for this hydrogen sensor could be fabricated on a silicon substrate through the use of standard surface-micromachining techniques [8]. Due to it's excellent mechanical properties, silicon nitride would be an appropriate structural material for the microcantilevers. This silicon nitride could be deposited using plasma enhanced chemical vapour deposition (PECVD). The palladium functionalization could then be deposited using thermal evaporation techniques and patterned using a metal liftoff technique. A polyimide such as PI-2610 would provide a suitable sacrificial layer to allow the cantilevers to be suspended a couple of microns above the substrate.

The nanomechanical movement of the cantilever could be measured using the external optical beam deflection technique [9], a cantilever as an optical waveguide technique [10], an optical differental detection technique [11], or the use of an integrated diffraction grating optical cavity technique [12].

IV. Conclusion

We have considered the use of hydrogen/silicon nitride bilayer microcantilevers as a tool for the detection of sub-milliTorr changes in the concentration of hydrogen. We found that nanomechanical movements of the cantilever tip are a good indicator of sub-milliTorr partial pressure changes of hydrogen in atmosphere. A technique for fabricating the hydrogen sensors was suggested.

Acknowledgment

We acknowledge the support from the Australian Research Council, Western Australian Node of the Australian National Fabrication Facility, and the Office of Science of the WA State Government.

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