# BATCH FABRICATION OF FLOWABLE COLORIMETRIC PRESSURE SENSING PARTICLES VIA SURFACE MICROMACHINING

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## ABSTRACT

The batch fabrication and test of artificial optical resonator slab-type micro particles (14 µm diameter, 0.7 µm gap) is presented as a means to map absolute pressure within microscopic environments. The pressure-sensing particles consist of a semi-transparent elastic polysilicon shell enclosing a reference vacuum cavity. The optical resonance frequency and the corresponding external pressure can hence be interrogated optically via reflectivity measurements. We demonstrate the measurement of internal pressures between 0-20 psi within microfluidic environments.

## INTRODUCTION

The velocity field within a microfluidic environments can be readily mapped via particle image velocimetry (PIV). Unlike PIV there is no equivalent technique for the complementary pressure field. Pressure fields have been indirectly inferred via observations of channel deformation [1] and fluorescence of $O_2$-sensitive pressure sensitive paints [2-4]. In this paper we report the direct measurement of internal chip pressures via colorimetric pressure-sensing microparticles implementing a particle imaging manometry (PIM) system.

## PRESURE SENSING PARTICLES

Each slab-type microparticle consists of a semi-transparent elastic shell enclosing a reference vacuum cavity as shown in Fig. 1. The thickness of the shell is designed such that the cavity gap and corresponding optical frequency is dependent on the
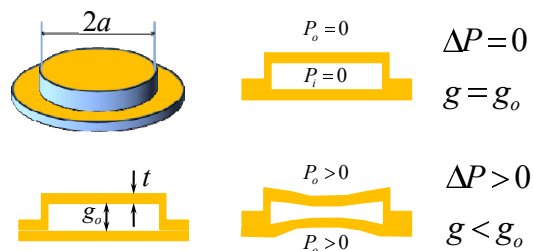


Fig. 1. (a) Schematic of slab-type spectroscopic pressure sensing hollow particle. (right) Note how the particle diaphragms deflect under a pressure differential thus changing the cavity gap.

external absolute pressure. The particle diaphragms thus form a Fabry-Perot resonator or etalon [5] of characteristic gap $g(\Delta P)$. In a simple Fabry-Perot resonator, at normal incidence the optical reflectance as a function of wavelength $\lambda$ is

$$R(\lambda) = \frac{1}{1 + \dfrac{T_d^2}{4R_d} \cdot \csc^2(\dfrac{2\pi g}{\lambda})} \qquad (1)$$

Where $T_d$ and $R_d$ are the diaphragm transmission and reflection coefficients, and $g(P)$ is the pressure dependent gap. The reflectance is zero when the argument of the csc() is $2\pi$ hence $\lambda_{min} = g(\Delta P)$. The minimum reflectance wavelength shift is hence related to the external pressure change.

## PARTICLE FABRICATION

Microparticles are batch fabricated on silicon wafers using the process shown in Fig. 2. The process flow
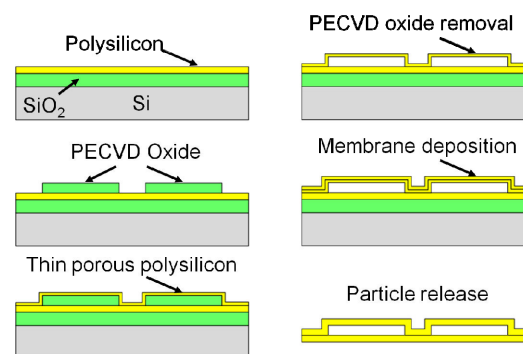


Fig. 2. Simplified pressure-sensing microparticle process flow. The particles can be released and stored in a methanol suspension.

requires just two lithography step. The first step is used to define the initial cavity gap, and the second is used to release the particle from its carrier substrate. The process starts with the growth of 0.6 µm of thermal oxide on silicon followed by 0.15 µm of undoped polysilicon. The particle cavity is next formed by the deposition of 0.7 µm of PEVD oxide and wet 6:1 BHF etching. Next the cavity oxide spacer is sealed with a 0.1 µm of porous polysilicon [6]. This material has small pores that permit the

sacrificial etch of the spacer oxide in concentrated HF. Next we deposit a .05 μm of regular polysilicon to seal the cavity at the deposition pressure of the polysilicon sealing film (~ 200 mT). In the final step, the periphery of the particle is lithographically defined and the polysilicon is etched down to the underlying oxide. Next the particles are released by sacrificial etching of the bottom oxide in concentrated HF. The particles are collected via a series of gradual dilutions in de-ionized $H_2O$. The particle density is slightly lower than the density of $H_2O$; hence a final dilution in methanol produces microparticles in solution. Fig. 3 shows SEM photographs of a slab-type microparticle array on a
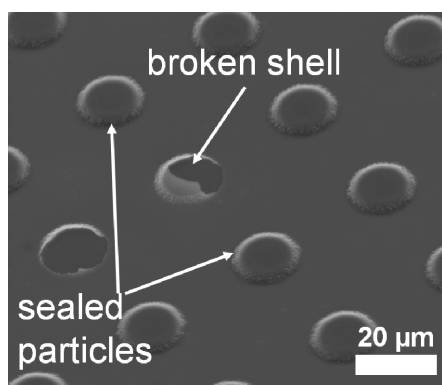


Fig. 3. SEM of slab-type 12 μm-diameter spectroscopic pressure-sensor sensor particles before their release.

carrier silicon substrate with a density of 310,000 particles per square centimeter.

## EXPERIMENTS

Fig. 4 shows an optical photograph of released 0.7 μm-gap, 14 μm-diameter slab microparticles on a glass substrate, and the corresponding optical reflectance at atmospheric pressure measured using an Ocean Optics spectrometer attached to a microscope. The particle reflectance shows characteristic dips at 0.52 and 0.65 μm. Fig. 5 shows the pressure dependence of a microparticle reflectivity. The spectral dip change can be correlated to the pressure-dependent compression of the optical cavity.
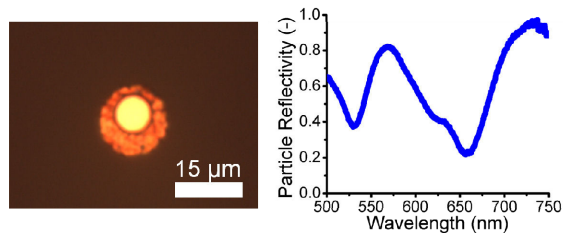


Fig. 4. Optical photograph of released 14 μm-diameter spectroscopic slab-type particles in a water suspension. (b) Measured microparticle reflectivity at normal incidence in air at atmospheric conditions.
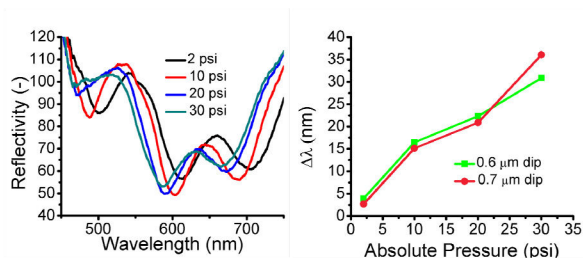


Fig. 5. (a) Measured particle reflectivity vs. pressure inside a liquid ($H_2O$) chamber. (b) Wavelength shift vs. chamber pressure for two different reflectivity dips.

In order to demonstrate the utilization of these devices we first introduced a large number of microparticles inside a test PDMS microfluidic chip with 100x25 $\mu m^2$ cross section which adhere to the capillary walls. The particle reflectivity was measured using the setup shown in Fig. 6(left) under
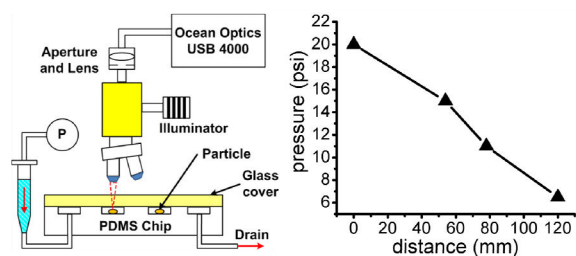


Fig. 6. (left) Experimental setup used for the measurement of internal pressure within a microfluidic chip. (right) Microparticle measured pressure vs. distance from chip inlet.

constant pressure driven flow of 3 cm/s. Fig. 6(right) shows the microparticle measured pressure drop vs. distance from the inlet. The measurements indicate an approximate linear pressure drop vs. distance.

## REFERENCES

[1] H. Lee, H. Lu, *Lab Chip*. 2009, vol.9 ,pp. 3345-3353.
[2] J. W. Gregory, K. Asai, M. Kameda, T. Liu, and J. P. Sullivan," *Proc. IMechE* vol. 222 Part G: *J. Aerosp. Eng.*, review Paper 249, 2008.
[3] T. Liu and J. P. Sullivan. *Pressure and Temperature Sensitive Paints*, 2005 (Springer).
[4] S. H. Ima, G. E. Khalil, J. Callis, B. H. Ahnb, M. Gouterman, Y. Xia, *Talanta,,* vol. 67 (2005) 492–497.
[5] Miller, M. F.; Allen, M. G.; Arkilic, E. Breuer, K. S.; Schmidt, M. A., *Transducers' 97*, vol. 2, pp.1469-1472, vol.2, 16-19 Jun 1997
[6] G. M. Dougherty, T. D. Sands, and A. P. Pisano, *IEEE JMEMS,* vol. 12, No.4, pp. 418-424, 2003.