# BIO-INSPIRED POROUS SILICON OPTICAL STRUCTURE FOR GAS SENSING

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**SUMMARY**
In this work we present a bio-inspired porous silicon structure for the optical detection of organic vapors. This structure, consisting of a periodic array of concave porous silicon multilayer stack, mimics the natural structure present on the *Papilio blumei* butterfly's wings. This structure gives rise to a vivid iridescent coloration and exhibit gas sensing capacity thanks to its porosity. We compared the shift in the optical reflectance spectrum due to vapour adsorption inside the fabricated structure to the shift of traditional porous silicon Bragg mirror and observed an enhanced response for the fabricated structures. Influence of both ethanol and 2-propanol was tested on the structure and the optical responses were compared.

## 1. INTRODUCTION

Gas sensing applications using porous silicon substrates have been widely reported for the detection of all kind of chemical species [1]. Among those, many optical detection devices have been developed using a multilayer-based approach for organic vapor detection [2-4]. Nature also provides us with naturally occurring nanoscaled multilayer structures with optical responses to chemical species in their environment, like the wings of *Morpho* butterflies of which gas sensing properties have been largely studied [5-6]. More recently, it has been demonstrated than the scales of the butterfly *Papilio blumei* exhibit a higher response to environmental refractive index changes with their concave multilayer structure [7]. Even though the natural structure has been replicated for its color properties, the replication processes are time-consuming, costly and the resulting sensitivity to chemical species is absent due to a lack of porosity in the synthesized replica [8-9].
In this work, we demonstrate a replication of this structure and its gas sensing properties by patterning and electrochemical etching of silicon to form a concave porous silicon multilayer structure. The detection of organic vapor is performed for ethanol and 2-propanol and its performances are compared to a porous silicon Bragg mirror.

## 2. EXPERIMENTAL RESULTS AND DISCUSSIONS

*Preparation of the porous silicon optical structure*
The concave porous silicon multilayer structure was prepared from p-type (100) silicon wafers (0.8-1.2 mΩ.cm). A 400 nm silicon oxide layer was deposited on the wafers by wet oxidation then slits were patterned by photolithography. The oxide mask was then opened using BHF (1:7 diluted in de-ionized water) to expose the silicon and the photoresist was stripped by oxygen plasma. Next, the patterns were etched in the silicon by wet etching using HNA to create the cavities. Finally the oxide mask was removed and the silicon samples were electrochemically etched in an HF:ethanol electrolyte (3:1 v/v) with a current density varying between 12.5 and 80 mA/cm$^2$ to obtain a porous silicon multilayer stack. The obtained samples can be seen in Figure 1.

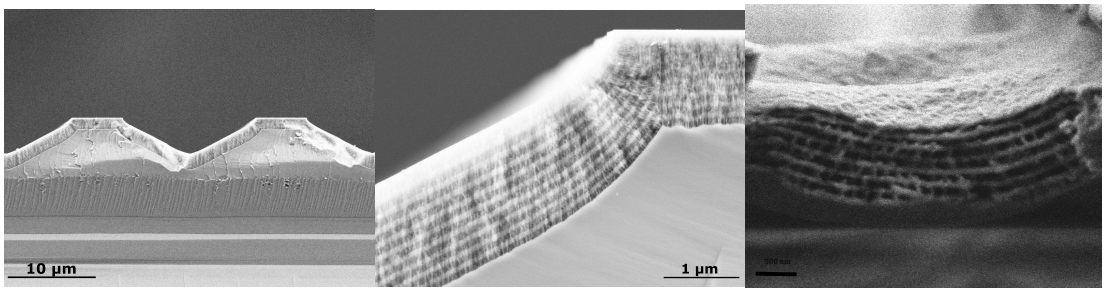



Figure 1: SEM pictures of the fabricated porous silicon multilayer structure (left and center) and *Papilio blumei* scale (right).

*Gas sensing optical characterization*
The experiments were performed at constant pressure in a stainless steel chamber with the sample and optical fibers located inside. The optical fibers, connected to the light source and the spectrometer are placed at a 15° angle from the normal incidence to the sample surface. In addition, the setup is composed of one pump allowing the purge of the chamber,

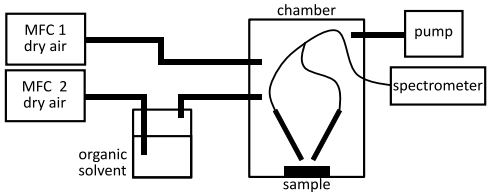



Figure 2: Setup for the optical detection of organic vapor in porous silicon samples.

one mass flow controller (MFC1) allowing the injection of dry air in the chamber and to keep a constant gas flow entering the chamber. A second mass flow controller (MFC2) was connected to a bubbler in order to vaporize the organic solvent and it into the chamber (see Figure 2). Prior to the measurements, the chamber was purged to ensure the sample desorption, and then it was filled with dry air until the working pressure (1.030 bar). The organic solvent vapor in a desired proportion was eventually injected.

*Optical measurements*

Figure 3(left) shows the optical reflectance spectrum (top) of the concave multilayer structure for an increasing concentration of ethanol vapor and the associated change in reflectance (bottom). The same measurements were performed for a porous silicon Bragg mirror with the same layers thicknesses as the concave structure, the results are shown in Figure 3(right). Comparing left and right, we observe an increased response to change for the concave porous structure. This increased response is probably partly due to an increased interaction volume per apparent surface. Figure 4 shows the sum of the difference in reflectance for all wavelengths depending on the quantity of injected organic vapor for both ethanol and 2-propanol. We observe an increased response for ethanol compared to 2-propanol, showing that we are able to differentiate between species.

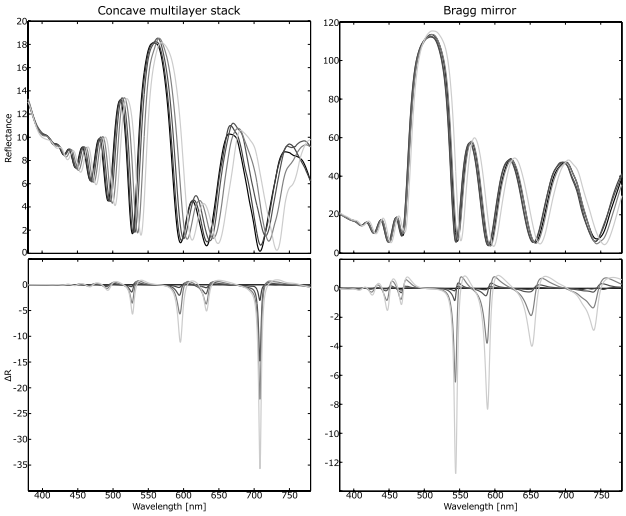



Figure 3: Optical reflectance spectra (top) and difference of reflectance spectra (bottom) for the detection of ethanol in a concave porous structure (left) and a Bragg mirror (right)

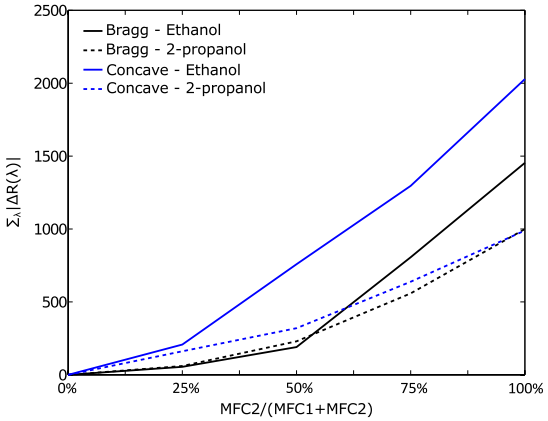



Figure 4: Sum of the difference in reflectance for all wavelengths due to vapor adsorption for ethanol and 2-propanol.

## 3. CONCLUSIONS

Concave porous silicon multilayer stacks mimicking the natural structure found on *Papilio blumei* wings were fabricated and the gas sensing properties of the fabricated structure were demonstrated. Its performances were compared to a porous silicon Bragg mirror showing an enhanced response to refractive index change and the capacity to discriminate between species was demonstrated for the detection of ethanol and 2-propanol.

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