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ScienceDirect
Procedia Chemistry 1 (2009) 1367–1370
Procedia Chemistry
www.elsevier.com/locate/procedia

Proceedings of the Eurosensors XXIII conference

A highly sensitive a-Si photodetector array with integrated filter for optical detection in MEMS

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Abstract

This paper presents a highly sensitive photo-detector array deposited on a glass substrate with an integrated optical filter. The active element is a vertically integrated hydrogenated amorphous silicon photodiode featuring a dark current of less than 1e-10 A/cm^2 for -3V bias voltage and a maximal quantum efficiency of 80% near 580 nm. The prototype was encapsulated and tested optically. It has a fill factor of only 44% which, however, can be easily increased to 90% using flip-chip bonding to an integrated electronic circuit for signal conditioning. The sensor is bio-compatible and can be integrated with other glass-based MEMS devices.

Keywords: Photo detection; Optical detector; Photodiode array; Dielectric filter; MEMS; Amorphous silicon

1. Introduction

Photo-detection is used in many fields of research and serves, e.g., for drug screening and fluorescence imaging in life sciences and for particle detection in material research. In general, these applications use solid-state photo-detectors which suffer from a number of disadvantages like modest sensitivity (limited fill factor), relatively large die size and limited flexibility in pixel shape which makes difficult their integration into MEMS devices. The development of photo-detection devices being directly deposited on MEMS alleviates these limits and facilitates the integration of photo-detection into MEMS for many different applications including the ones described above. In the field of deposited photo-detectors, the thin film on ASIC (TFA) technology is used, and is based on the deposition of a photo-sensitive layer on top of a read out integrated circuit [1], [2]. The pixels have an improved fill factor, but their size, shape and orientation still depend on the underlying ASIC. Furthermore, a biocompatibility requirement sets a supplementary constraint to the already critical post-processing steps. Another approach is to use a different substrate than the ASIC for thin film deposition, and to connect the photo-detector array to the ASIC by means of bonding or flip-chip with high density solder bumps [3] if high resolution and high fill factor is desired. This approach does not need critical post-processing of the ASIC, and allows potentially better biocompatibility.

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doi:10.1016/j.proche.2009.07.341

Furthermore, other kinds of MEMS sensors can be implemented into the substrate through patterned growth techniques, thereby expanding the range of possible applications of the device.

2. Operation principal

Our proposed approach is depicted in Fig. 1. It consists of thin film patterned photodiodes deposited on the back side of a Quartz substrate. The front side can be micro-machined and/or assembled to form part of any MEMS which is in need of photo-detection. The quartz thickness can be reduced so that any sample (biomaterial or other) located in the top side is in almost direct contact with the detector surface, while benefitting from the excellent biocompatibility of glass. A highly selective dielectric filter can be integrated between the glass substrate and the deposited photodiodes, to permit wavelength selective measurement of photon emission. The advantages of this approach are its inherent simplicity and a high sensitivity due to maximal optical aperture and fill factor.

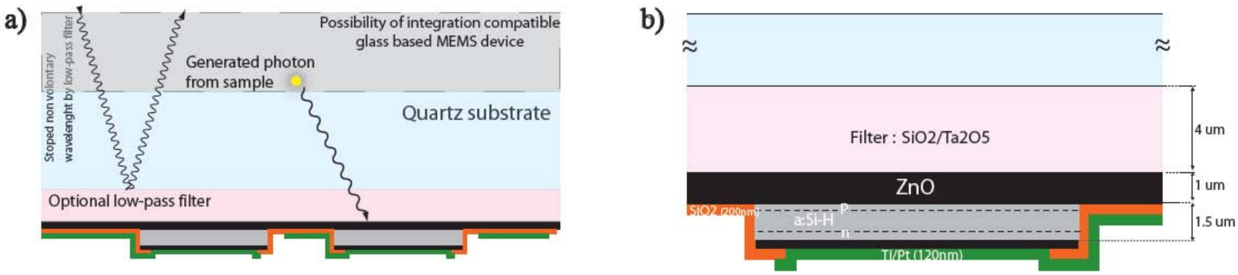

Fig. 1. (a) A cross-section of the proposed sensor device with 500 um thick Quartz used as substrate; (b) A zoom on a single pixel with corresponding layers, connected to external world by Ti/Pt metal layers.

3. Fabrication

3.1. Filter

An interference filter is used to block undesired wavelengths from reaching the photodiodes, which is an important requirement for applications such as fluorescence imaging. For this, a dielectric filter is used. It shows excellent filtering properties, is resistant to heat, has a high homogeneity and is compatible with the deposition process of the next layers. The low-pass filter was deposited by MSO-Jena (Germany) and consists of plasma ion assisted deposition of multiple dielectric layers of SiO_2 and Ta_2O_5 with a cut-off wavelength of 525 nm and a total thickness of 4 µm. It exhibits excellent properties: high attenuation (>99.99%) outside and high transmission (>90%) within the pass-band. The frequeny response is shown in Fig.2a.

3.2 Photodiode

The deposited photodiodes were realized in hydrogenated amorphous silicon. Being issued from the solar cell research, they show excellent characteristics in terms of quantum efficiency (as high as 80% between 500 and 600 nm), low dark current (1e-10 A/cm^2 for -3V polarization) and yield [4]. They were fabricated by using in-house methods and facilities of PVLAB at EPFL, consisting of VHF PE-CVS (very high frequency Plasma Enhanced Chemical Vapor Deposition). A 1 µm thickness ZnO transparent oxide layer was deposited on the dielectric filter and serves as common anode. A 1 µm a-Si:H layer (the photodiode) was then deposited, followed by a 150 nm ZnO for electrical contact with further metal layers.

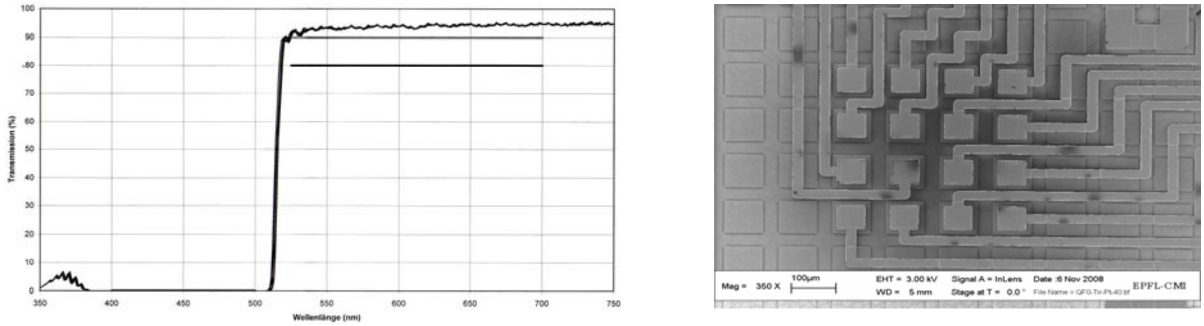

Fig. 2. (a) frequency response of deposited dielectric filter, provided by MSO-Jena; (b) SEM picture of an array of sixteen photodiodes.

3.3 Fabrication process

The photodiode patterning was done by a combination of wet and dry etching for the different layers. A 2 μm positive photoresist was coated and patterned on top of ZnO. Through the opening windows on the mask, the thin ZnO layer was etched by using diluted HCL (1:200). The a-Si:H layer was etched away with SF6 by ICP technique. The photoresist was suppressed by remover and plasma oxygen was done to clean the surface.

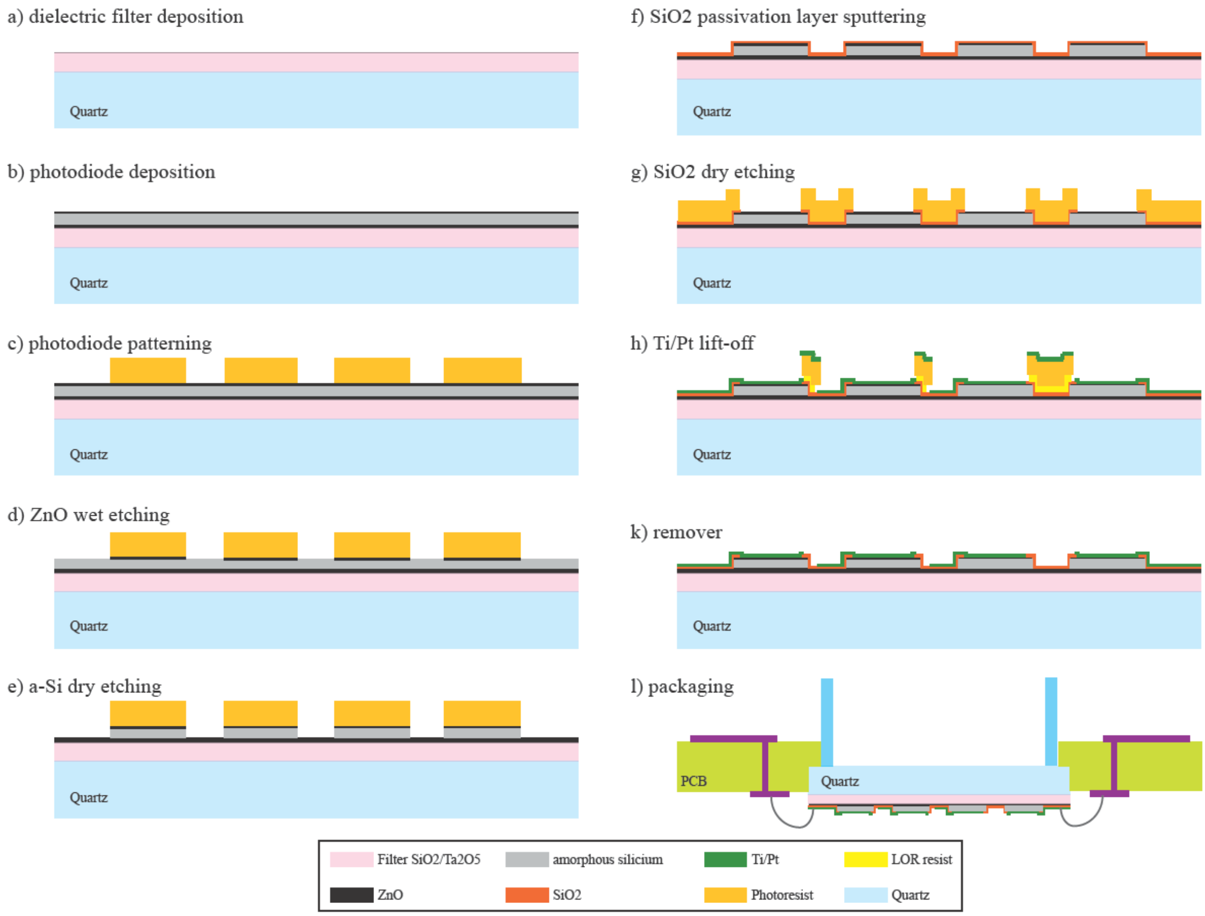

Fig. 3. (a) dielectric filter deposition composed by multi layer of Ta_2O_5/SiO_2; (b) a-Si:H deposition ; (c) photolithography for pixel cutting off; (d) ZnO wet etching; (e) a-Si:H dry etching; (f) SiO_2 passivation layer deposition at low temperature by sputtering; (g) photodiode back side pattering and silicon oxide dry etching; (h) Ti/Pt deposition by lift-off photolithography; (k) clean remain mask by remover; (l) device packaging.

Once the photo diodes were patterned, a 200 nm passivation Silicon dioxide layer was sputtered on top of the photodiodes in order to create an electrical isolation layer. By using conventional photolithography and dry etching techniques, the Silicon dioxide was etched away on the back side of each pixel. A Ti/Pt (20 nm/100 nm) metal connection layer was deposited by lift-off technique to make a connection between the back of each photodiode and the external wire bonding pads. The detectors feature a fill factor of 44%, mainly limited by the space required for the metal connections. This number could be easily increased to 90% by using flip-chip and high density solder bump techniques. Each wafer contains 32 devices of 100 mm^2 each. They were separated by wafer dicing and packaged for a biological application. For this, a PCB was designed, and each device was glued and connected to the PCB pads by wire bonding. A cylindrical container was finally fixed on the top to form a chamber for long-term biological tests.

4. Experimental Result

Relative quantum efficiency was measured to verify the filter functionality and the efficiency of pixels. Fig.4a. shows relative QE for two pixels with and without filter. Filter functionality was approved by measuring cutting frequency at 525 nm. In each device, approximately around 40% of pixels are functional and good homogeneity was observed for different pixels. For optical tests, the devices were encapsulated and bonded on a PCB and connected to an external electronic circuit.

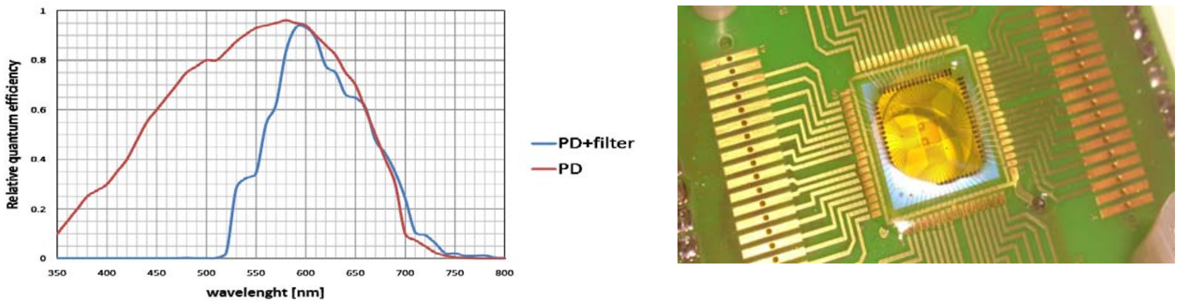

Fig. 4. (a) Relative quantum efficiency measured for one pixel; (b) device was packaged by gluing and connected by wire bonding to a PCB.

5. Conclusion

The concept and microfabrication steps of an optical photodetection system including optical filters for glass-based MEMS was presented. The system performs high light sensitivity, potentially high spatial resolution and high biocompatibility. The fabrication technique can be used to construct, on the same structure, hybrid and high density detectors for multi-parameter, long-term measurement of biological preparations. The sensor is bio-compatible and can be integrated with other glass-based micro-fabricated devices such as micro-fluidics, chemical and biological devices in which photo-detection is a desired feature.

Acknowledgements

The device presented in this paper was fabricated in the CMI and PVLAB at EPFL. This work was supported by the Swiss National Science Foundation (SNSF), Grant 113976.

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