SCINTILLATING MICROCAVITIES FOR X-RAY IMAGING SENSORS

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Abstract — *Over the last years several prototypes of detectors for digital radiography, based on different approaches, have been developed. One those approaches is based on scintillating crystals, which convert the x-ray energy into visible light that will be detected by photodetectors. The biggest difficulty of this kind of detectors is the fact that the produced visible light must be guided to the photodetectors. This can be achieved through coating of reflective material on and around each scintillator. This article describes the fabrication process of an x-ray detector based on scintillators and walls of a reflective material, aluminum, which guide the visible light to the photodetectors placed below the scintillators.*

Key Words: *X-ray detector, scintillator, SU8, micromachining.*

INTRODUCTION

The digital x-ray systems are substituting the silver halide films of the traditional radiographies in almost all applications, allowing the acquisition and processing of images in real time, eliminating time losses, wastes and pollution caused by the traditional radiographies.

Basically, there exist two main methods to construct x-ray detectors for digital radiography, known as direct and indirect methods [1]. In the direct method, a photoconductive material absorbs the x-rays and converts them into an electric current. Its main disadvantage consists on the fact that it is necessary a relatively high electric voltage in order to polarize the photoconductor, which becomes dangerous for some applications, as for example in dental radiography.

In the indirect method, a scintillator is placed on the top of a photodetector [2-4]. The scintillator absorbs the x-ray energy and produces visible light, which is detected by the photodetector, producing an electric current. One of the simplest techniques to construct an x-ray imaging detector based on this method consists in the placement of a scintillator on the top of a photodetector array, such as it is schematized in figure 1(a).

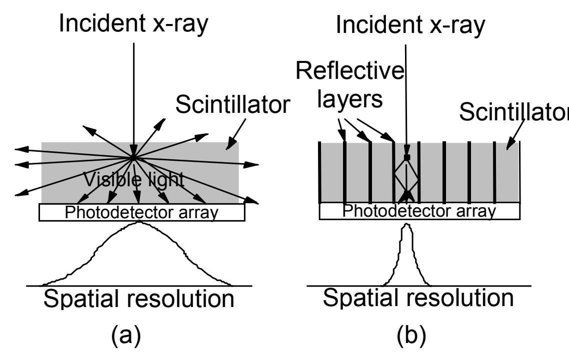


Figure 1: Effect of reflective layers on the spatial resolution: (a) a single scintillator; (b) scintillators separated by reflective layers.

The main problem of this method is that the spatial resolution of the device is approximately equal to the thickness of the scintillator.

By one hand, the increase of the scintillator thickness is desirable to stop almost all the incident x-rays, by the other hand, it is desirable to keep it as thin as possible to obtain a good spatial resolution.

Scintillating light guides separated by reflective layers can be used to increase the thickness of the scintillator without decreasing the spatial resolution, as is shown in figure 1(b) [4]. In this case, the light yield by each scintillator is guided to the corresponding photodetector by the reflective layers. The spatial resolution becomes approximately equal to the distance between the reflective layers.

There are several kinds of photodetectors that can be used in this application, namely the photodetectors manufactured in CCD technology, the amorphous silicon photodiodes, the photodiodes or phototransistors manufactured in bipolar technology, the avalanche photodiodes, the photomultiplier tubes and the photodiodes manufactured in CMOS technology [1].

SYSTEM DESCRIPTION

Figure 2 shows a schematic representation of the detector structure. The photodetectors consist on a CMOS photodiode array. The scintillators are placed above the photodetectors. In this case, the chosen scintillator was the CsI:Tl, due to its high light yield and relatively high density and atomic number of its elements (which is necessary to absorb the x-rays).

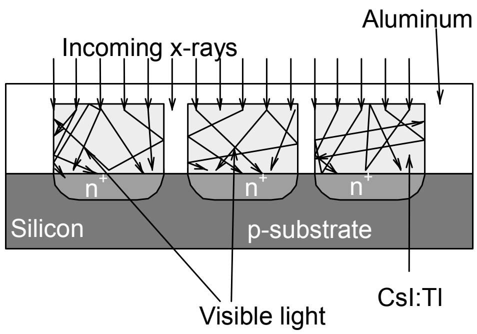


Figure 2: Schematic representation of the detector structure.

A reflective material is then used to coat the scintillator. It works like a light guide avoiding the visible light dispersion and the interference between each neighbor pixel. Moreover, it improves the spatial resolution as well as it increases the intensity of the transmitted light to the photodetectors. In addition, the quantity of the incoming x-rays radiation can be reduced while keeping the same sensitivity of the photodetectors signal readout. This material must have a low density and a low atomic number to allow the penetration of the x-rays. The aluminum is a good candidate. In this case, the x-rays cross the reflective material placed on the top and reach the scintillators, where they are absorbed. For each x-ray absorbed photon, many visible light photons are produced, traveling in all directions. Some of them arrive directly at the photodetector, while others reach the reflector. After some reflections, disregarding the losses in the reflection, almost all the visible light photons reach the photodetector.

An interesting approach to coat the scintillators is described by Kleimann et. al. [5]. In this case, the image detector is composed by two dies. The photodetector matrix constitutes the lower one. The top one consists in a silicon die with cavities opened by means of DRIE (Deep Reactive Ion Etching). The scintillator is placed inside of these cavities using thermal evaporation or by applying a pressure.

Other approach that uses only one silicon die is described by Allier et. al. [3]. In this case, the cavities are opened with DRIE and avalanche photodiodes are fabricated on the backside of the die.

These approaches are not very efficient since the silicon is not a good reflector.

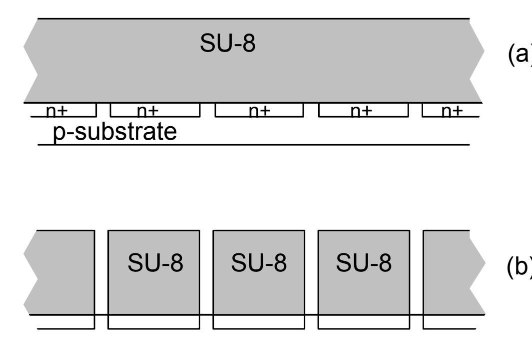
A silicon die bulk micromachined with KOH etching has been also attempted [6]. The photodiode is fabricated at the bottom of the cavity. In this case, the sidewalls are not vertical and the dimensions of the device would be too big to obtain an array with good spatial resolution.

A similar approach uses the CsI:Tl scintillator grown with a columnar structure which is formed when evaporated under special conditions [7,8]. This structure also guides the light yield into the CCD (or another photodetector), but it has some limitations, such as:

- The CsI:Tl must be evaporated and annealed. This fabrication step may not be compatible with the photodetector technology.
- Other scintillating materials, interesting for some applications, namely computed tomography and nuclear medicine imaging do not form a columnar structure when evaporated. Therefore, they cannot be used within this approach.

FABRICATION PROCESS

The developed approach of the x-ray detector is composed by an array of scintillators and an array of photodetectors underneath. The scintillators are coated by an aluminum layer to form light guides, as it was seen in the last section.



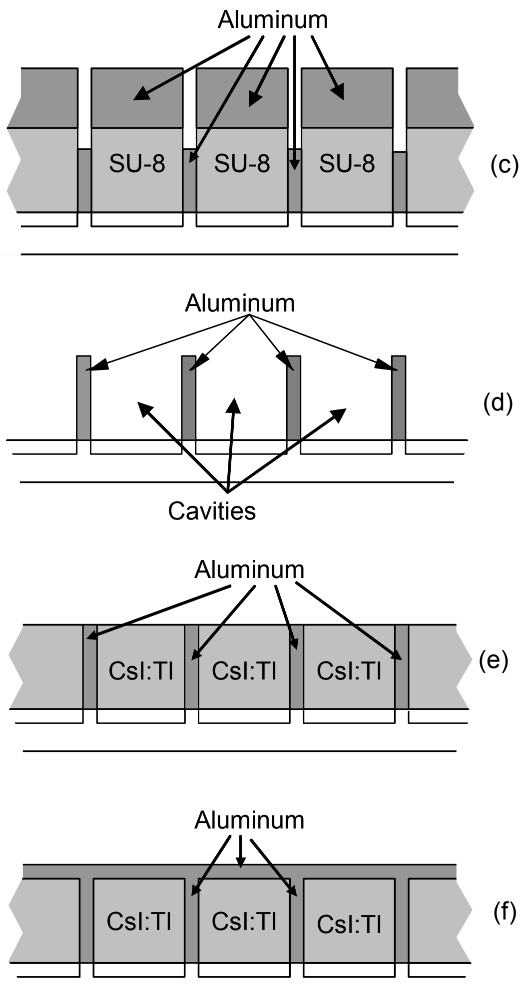


Figure 3: (a) A SU-8 photoresist is placed above the CMOS detector array by spin-coating. (b) The photoresist is patterned and (c) an aluminum layer is evaporated. (d) The SU-8 is totally removed. (e) A layer of CsI:Tl is deposited inside the cavities and (f) finally an aluminum layer is evaporated on the top of the device.

The following paragraphs explain the scintillator array fabrication inside the aluminum walls. A sacrificial layer of SU-8 photoresist is spinned of over the CMOS photodetectors array (figure 3(a)). This material is chosen once it enables deep structures with very low sidewall roughness, which is suitable for the required cavities. Moreover, the patterning of the SU-8 columns requires only a negative mask made of a regular transparent foil (like the one used in printed circuit boards), which is a low cost process. After UV exposition, a suitable solvent (propylene glycol monomethyl ether acetate) dissolves the unexposed resist, and SU-8 columns are formed on top of the photodetectors (figure 3(b)).

The next step is to deposit, by PVD (Physical Vapor Deposition) techniques, the aluminum layer over the entire array (figure 3(c)). Then, the SU-8 columns are removed and therefore the aluminum on top of those columns. The final aspect is a set of cavities with aluminum walls, which are on top of the photodetectors (figure 3(d)). Then, the scintillator is placed in those cavities. The scintillator can be placed either by PVD techniques or by a hot/cold mechanical pressure (using a crystal powder scintillator) (figure 3(e)). Finally, an aluminum layer is deposited, by PDV, on top of the scintillator. The final result can be seen in figure 3(f).

RESULTS

Figure 4 shows the patterned SU-8 photoresist above the silicon die.

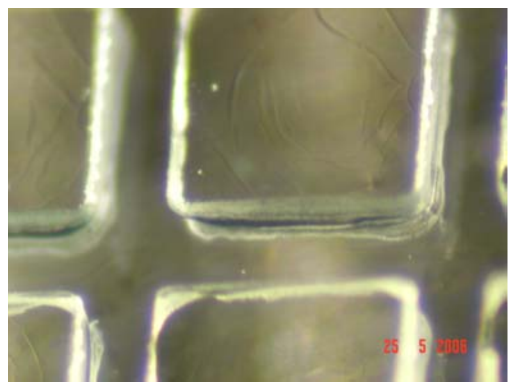


Figure 4: Picture of the SU-8 pattern. It corresponds to the step described in figure 3(b).

Figure 5 shows the same pattern of figure 4 after the deposition of the first aluminum layer.

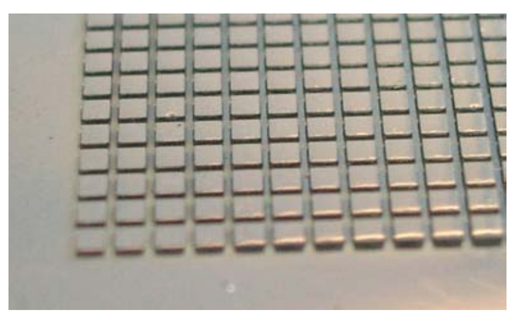


Figure 5: Picture of the die after the evaporation of the aluminum. It corresponds to the step described in figure 3(c).

Figure 6 shows the aspect of the microcavities formed after the removal of the SU-8 columns.

This picture corresponds to the fabrication step described in figure 3(d).

Figure 7 shows a detail of a cavity. Its dimensions are $400\ \mu m \times 400\ \mu m$ and the thickness of the aluminum wall is 100 µm. It is not possible to see in the figure, but the depth of the cavities is also 100 µm.

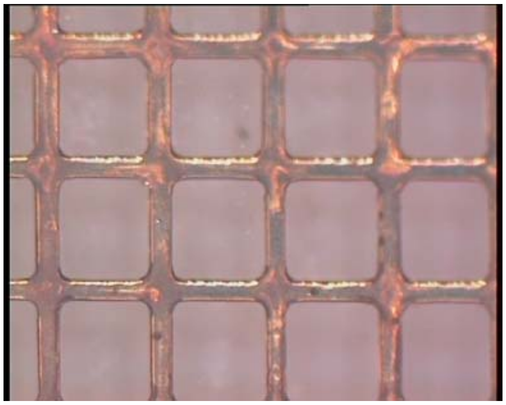


Figure 6: Microcavities formed after the removal of the SU-8. It corresponds to the fabrication step of figure 3(d).

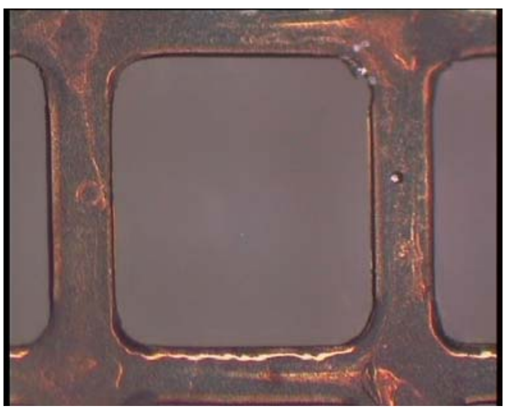


Figure 7: Detail of a microcavity. Its dimensions are $400\ \mu m \times 400\ \mu m$ and 100 µm deep. The thickness of the wall is 100 µm.

CONCLUSIONS

The spatial resolution of x-ray detectors based on scintillating crystals to digital radiography can be improved by confining the scintillator with a reflective material such as aluminum. A method for preparing cavities of reflective material, where the scintillator will be placed has been presented. The advantages of the proposed method are the low cost and the regular shape, homogeneity and reproducibility of the cavities. Further advantages of the method are the good verticality of the achieved sidewalls and the low surface roughness. Once the cavities are fabricated, the scintillator can be simply evaporated into the cavities or introduced by applying external pressure. Further miniaturization beyond the sizes obtained in the constructed prototype is also allowed by the presented method.

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