MEMS TECHNIQUES APPLIED TO THE FABRICATION OF ANTI-SCATTER GRIDS FOR X-RAY IMAGING

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ABSTRACT

This paper reports a promising method for the fabrication of lead collimators for x-ray radiology applications. The fabrication method is based on arrays of macropores etched into a silicon wafer using an electrochemical process. The macropores are filled with lead and the silicon substrate is removed subsequently. The macroporous silicon structure thereby acts as a sacrificial layer. The use of MEMS techniques enables us to decrease the size of the structure by one order of magnitude compared to conventional collimators, thus increasing the optical resolution of the x-ray system.

INTRODUCTION

In radiology a collimator located between the patient and the photographic plate is used to absorb scattered x-ray photons, which otherwise would blur the image. Such collimators are termed anti-scatter grids. State-of-the-art grids consist of alternating layers of lead as absorbing medium and paper or aluminum as transparent medium. Due to the fabrication process for which these layers are mechanically stapled and glued together the achievable number of layers per millimeter is about 3 to 6. Due to this limitation the anti-scatter grid has become a limiting factor for the image quality of today's radiology systems. These drawbacks can be circumvented by a new fabrication process for anti-scatter grids based on macroporous silicon. This process enables us to increase the number of absorbing elements per millimeter by an order of magnitude.

FABRICATION PROCESS

The fabrication process combines a mould prepared by semiconductor manufacturing techniques with lead casting. A schematic view of the process of the new anti-scatter grid is given in Fig. 1. First etch-pits in a desired pattern are formed on the silicon wafer surface by photolithography and subsequent alkaline etching (a). These etch-pits serve as initiation sites for the subsequent electrochemical etching process, which generates straight pores of 600 µm depth and 8 µm diameter (b). The etching technique and its different applications have been described in detail elsewhere [1,2]. Next a 100 nm silicon nitride layer is deposited onto the pore walls a by chemical vapor deposition (c). Now the mould is ready for lead casting. In order to obtain a sufficient filling of the pores the sample wafer is evacuated in a pressure tank. Under vacuum pressure the wafer is then immersed in liquid lead. Due to capillary forces the overpressure required to fill the pores is in the order of 5 bar. The wafer is then pulled out of the liquid lead and the lead inside the pores solidifies under pressure. After the pressure in the tank is reduced to ambient pressure the wafer is removed (d). For the x-ray imaging in the low energy regime (up to 30keV) the silicon absorption is undesirably high. It is therefore favorable to remove in part of the silicon. In order to etchback the bulk silicon the nitride on the wafer backside is removed. Then about half of the total thickness of the bulk silicon wafer is etched-back in hot KOH. The nitride layer inside the pores serves as an etchstop layer during this process (e). A SEM image of a sample at this stage of the fabrication process is shown in Fig. 2. Due to volume reduction of the lead during solidification, the pore tips remain free of lead, as can be seen in Fig. 3. The CVD-nitride serves not only as an etchstop layer but also as a mechanical support for the soft lead pillars. During drying after the etch-back for example pure lead pillars would inevitably stick together due to capillary forces at the liquid-gas interface. The fragile structure of the free-standing lead pillars is then further stabilized by an epoxy resin fill (e). If a total removal of the silicon is desirable, the nitride on the front surface is removed, too, for example by plasma etching. Then the etch-back and the resin fill procedure is repeated.

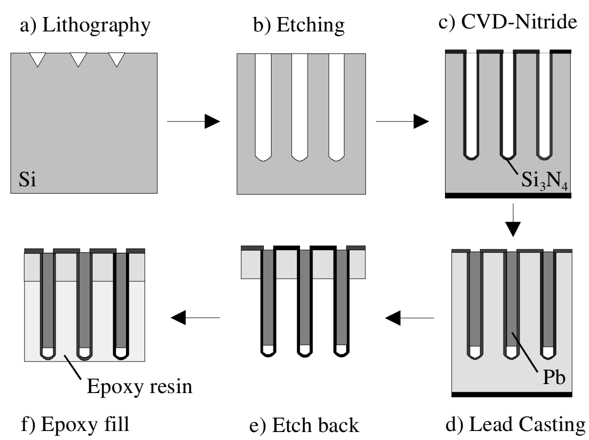

Figure 1: Schematic view of the fabrication process for the new anti-scatter grid

RESULTS

Simulations for the structure described above assuming a application as mammography grid (28keV, Mo-Anode) have been carried out. The calculation has been split into two steps. First the energy spectrum and the angular distribution of the scattering radiation have been calculated by means of a Monte-Carlo simulation. Then the transmission of the assumed grid has been simulated for the above calculated energy spectrum in dependence of the azimuthal and the polar angle. Finally the results are integrated to yield the grid parameters. The obtained simulated values of primary transmission as well as scatter transmission show that the new micro-scatter grid is equal to or better than conventional grids. These calculated results of transmission are supported be X-ray measurements using the standard measurement conditions for anti-scatter grids, as laid down in IEC-61953 and DIN-6826.

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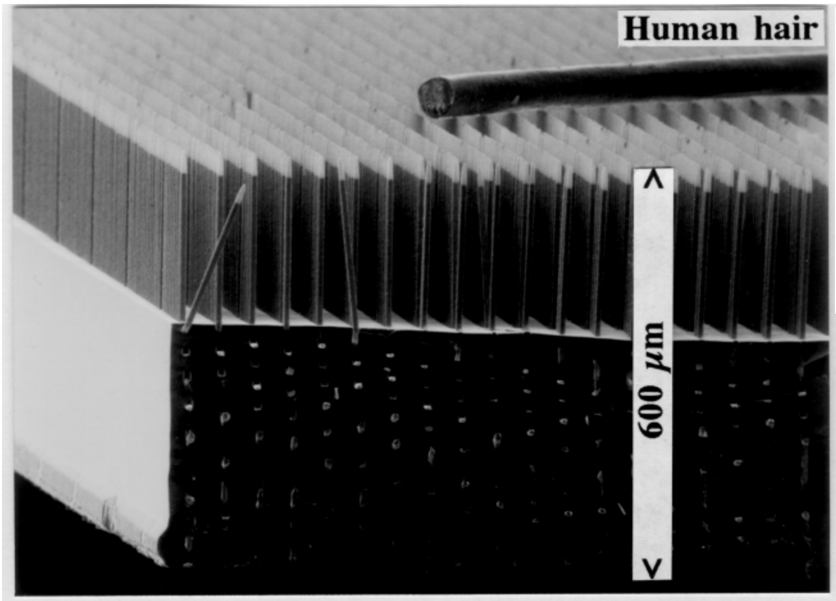

Figure 2:
SEM micrograph of the silicon wafer after etch-back of 265μm bulk silicon. A hair is shown for size comparison. The lead pillars are arranged in lines using a close spacing within the lines (pitch: 16μm) and a large spacing (pitch: 48μm) between the lines.

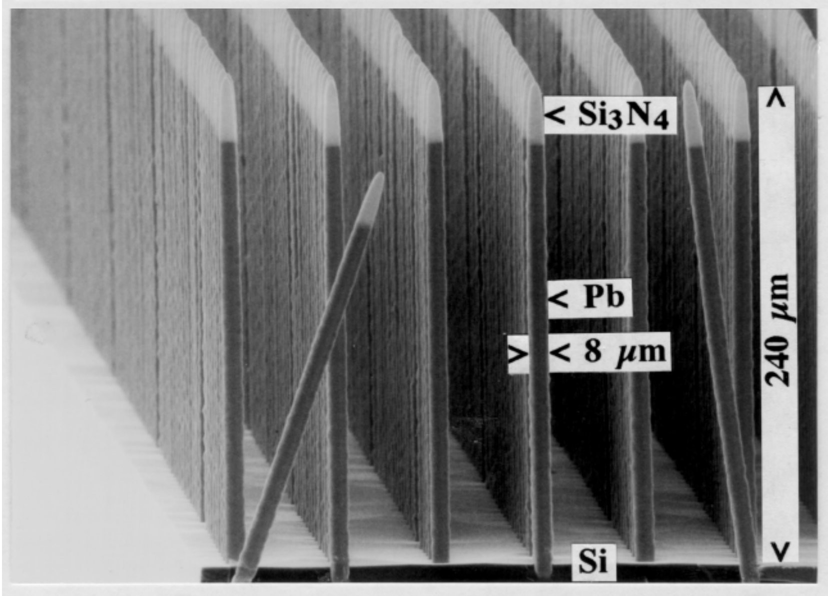

Figure 3:
SEM micrograph of the free-standing lead pillars. The front pillars appear distorted due to mechanical damage caused by cleaving of the sample.

The first x-ray images of the new anti-scatter grids show that the lines of lead pillars, as shown in Figs. 2 and 3, are not resolved by the naked eye, due to their narrow spacing (48μm). This is in stark contrast to conventional grids (spacing: 340 μm) which have to be moved during the exposure in order to avoid imaging of the lead lines. Due to their tight spacing and the high precision of the pattern, the new grids are favorable for combination with electronic imaging systems.

The preliminary x-ray images, however, were not found to satisfy the requirements concerning homogeneity. x-ray images of conventional grids show a homogenous grew-tone over the full size of the grid, while visual inspection of x-ray images of the new grid showed darker and brighter areas. These inhomogeneities most probably originate from distortion of the lead elements caused by stresses between the epoxy resin and the silicon substrate during thermal cycling between room-temperature and hot KOH (80°C). Processing with a lower thermal budget as well as the use of different resins are currently under investigation to circumvent this problem.

CONCLUSIONS

A MEMS based fabrication process for anti-scatter grid is presented which enables us to produce grids of a unequalled narrow spacing of absorbing elements. Preliminary results show that the performance of these grids compares well with conventional anti-scatter grids. The homogeneity of the new grids has to be improved for application in x-ray imaging systems.

REFERENCES

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