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1.6.2: Microfabrication II

Fabrication of multi electrode array structures for intra-neural stimulation: Assessment of the LIGA method.

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Abstract - The fabrication of the basic structure of needle electrode arrays by means of the LIGA method is investigated. To be able to contact all needle electrodes individually, the arrays were fabricated on silicon wafers with a patterned interconnection layer. Though further improvement of the process is needed to increase yield of the very slim structures, this approach shows the feasibility of combining LIGA with silicon technology, thereby offering a useful tool for the fabrication of neural prostheses.

INTRODUCTION

For the purpose of selective intra-neural electrical stimulation devices consisting of arrays of separately addressable thin electrode needles are required. For instance for selective stimulation of the rat EDL muscle a full device would consist of 128 needles, each one typically 20μm thick and several hundreds of microns tall and positioned on a 120μm grid [1].

The fabrication of the basic "hairbrush" structure of such devices is still a challenge with current technologies because of the high aspect ratios required. The LIGA method (German acronym for Lithographie, Galvanoformung, Abformung), which is known for its high aspect ratios [2], was tested for the production of these devices, as an alternative to for instance Reactive Ion Etching or mechanically sawing the needles. The main steps of LIGA are deep X-ray Lithography of thick PMMA (polymethylmethacrylate) with a synchrotron radiation source (typically 0.8-2 GeV), followed by electrodeposition of a metal (usually nickel) in the resist cavities. In the last (though optional) 'Abformung' step the nickel parts can be used as mould inserts or embossing tools for mass reproduction of polymer structures.

An important issue with these kind of neural interfaces is contacting all the electrodes separately. To facilitate contacting, the presented design uses a Si_3N_4-insulated silicon substrate covered with a 8μm thick copper interconnection layer. The nickel needles are grown on the end pads of these leads and have all the same height in this study.

METHODS

Because of compatibility with other processes, silicon wafers were used as a substrate. With PECVD (Plasma Enhanced Chemical Vapor Deposition) 500nm Si_3N_4 and 100nm SiC were deposited to serve as an insulation for the interconnection layer, followed by sputtering of 100nm Ti and 100nm Cu for the seed layer in the electroplating process. The interconnection layer was obtained by electroplating 8μm copper from a copper sulfate electrolyte through 12μm thick resist patterned with UV lithography.

The wafers were attached to 5 mm thick titanium wafers with wax, in order to be able to separate them again. Contacts for the electroplating process have to endure the unpolimerized MMA and were therefore made with Pb/Sn plated copper foil. These titanium wafers are being used routinely in the LIGA process because of the adhesion of PMMA to the roughened and oxidized titanium. As the 4" titanium wafer exceeded the diameter of the silicon wafer, the PMMA that was cast next, was able to adhere to the titanium, thereby alleviating problems with adhesion of PMMA to the polished silicon wafer. The PMMA was tempered and milled down to the desired thickness.

For the aligned X-ray exposure a special LIGA mask was made, which uses 12μm gold absorber pattern on an optically transparent mask blank consisting of 4.5 μm Si_3N_4 membrane (standard LIGA uses beryllium mask blanks). The exposures have been performed at the DCI storage ring (Orsay/France) using an X-ray Scanner (Jenoptik GmbH) with an external alignment system. After developing, the needles were electrodeposited from a nickel sulfamate based electrolyte. As plating is never uniform, the overgrown structures were lapped down to the level of the PMMA. A second irradiation and developing step was needed to remove the cross-linked PMMA before the Cu/Ti seed layer is to be etched in ammonium persulfate and hydrofluoric acid respectively. Before the devices are to be used, coating of the needle shafts with Si_3N_4 and selective electrodeposition of iridium oxide on the needle tips is projected.

RESULTS

Basically, the design comprised cylindrical and square columns, with diameters between 15μm and 50μm. Tests were done with 200μm, 250μm and 500μm thick PMMA. After tempering the PMMA, the wafers were slightly bend convex (deflection approximately 15μm), which is a result of

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mismatch in thermal expansion coefficients between Si, Ti and PMMA. Though other substrate materials can be considered, the problem will always remain to some extent, and thereby limit the maximum PMMA thickness and needle length. Using the described method, excellent adhesion of casted and crosslinked PMMA on polished silicon wafers was obtained.

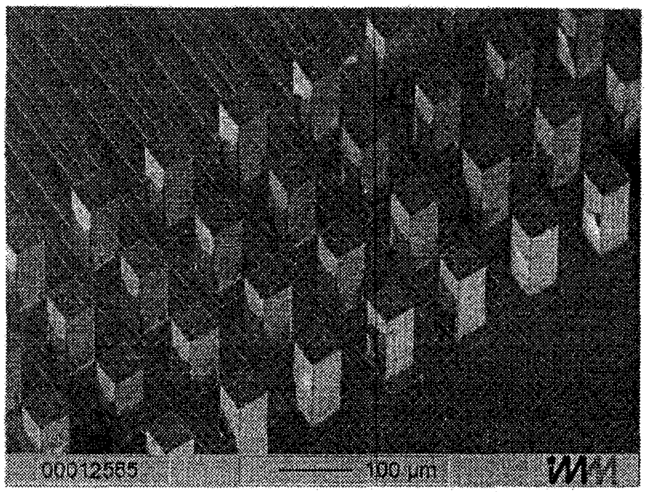

Figure 1: Multi electrode array with 200µm tall needles, realized with aligned x-ray lithography (LIGA) on silicon substrate with 8µm Cu interconnection wiring. The dark skins on the side walls are PMMA residues which can be removed with an O_2 plasma treatment.

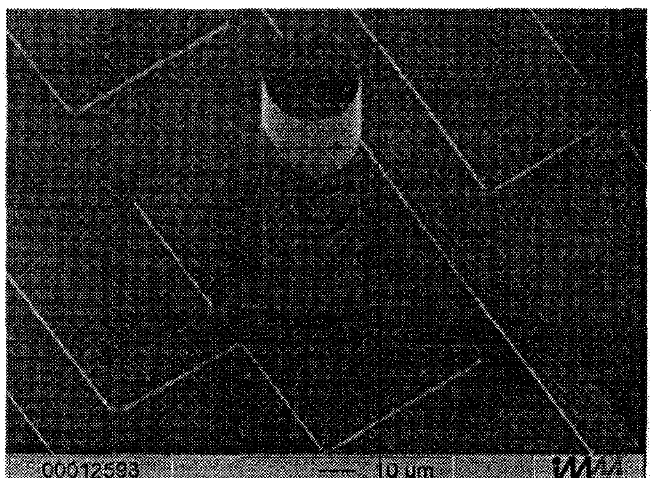

Figure 2: SEM photo of a 25 µm diameter column on 8µm thick copper pad. The defects are characteristic for the cylindrical structures.

After developing and electroplating the results were promising for the square structures (figure 1) down to 20µm column width and 250µm height. However, only a small amount of the cylindrical structures was completely filled with nickel. A SEM (Scanning Electron Microscopy) inspection after removal of the PMMA showed a large difference between square and cylindrical columns which is probably caused by effects related to surface tension (wetting) during developing and electroplating. The trapping of gas bubbles is more likely to occur in cylindrical than in square channels in the PMMA, and therefore a majority of the square columns were plated successfully and virtually every cylindrical column failed. The 500µm thick sample results were worse, but the same tendency appeared. At most sites where a column was supposed to be, the nickel had started to grow in a whisker shaped way, but stopped successively.

Discussion

Using the external alignment system, an adequate overlay accuracy in the samples was achieved. Since the optical transparency of PECVD Si_3N_4-membranes drops drastically after hard x-ray exposure, which may be attributed to a small amount of evolving hydrogen [3], alternative mask blank materials, such as diamond, should be considered. As a consequence, Si_3N_4-membranes can only be used for a limited number of exposures.

When feature size decreases, the yield of the electroplating process decreases as well, especially for the cylindrical columns. The design should be adjusted to optimize the yield: preferably only square structures should be used. Current investigations cover the field of the developing and electroplating process of these narrow channels, in order to achieve a better yield of 500µm tall, 20µm thick needles.

Whether a moulding process for mass reproduction, which avoids the expensive synchrotron irradiation, is feasible, can be questioned as the produced columns may be too fragile to be used as mould inserts or embossing tools.

Conclusions

We reported on initial results applying the LIGA technique, especially the aligned deep x-ray lithography process, for the structurization of processed silicon substrates. In general the problems encountered were a result of the type of structure and electroplating inside small channels in thick PMMA. The principle of aligned LIGA on silicon showed no fundamental problems. The adhesion of PMMA to the polished silicon substrate proved no prevailing problem in this approach in which the PMMA could adhere to the titanium.

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