International Conference
1ST International Conference on Innovations, Recent Trends and Challenges in Mechatronics, Mechanical Engineering and New High-Tech Products Development
MECAHITECH'09

Bucharest, 8-9 October 2009

Fabrication of Microtextured Surfaces by Hot Embossing

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ABSTRACT

The paper deals with the hot embossing technology applied to obtain microstructures of micro pyramid type, found in solar cell or LCD designs due to the enhanced brightness of these structures. Hot embossing is a lithographic method by which the pattern of a certain structure is transferred under pressure from an original onto a polymer substrate. In our process, the mold insert was fabricated on silicon wafer by anisotropic etching. A good replication of microstructures in films of PDMS (Polydimethylsiloxane) has been demonstrated.

INTRODUCTION

Polymeric micro-electro-mechanical systems (MEMS) are important as low–cost alternatives to silicon or glass-based MEMS technologies for a range of present and future commercially viable products in the field of life science, micro-optics, display technology and so on.

The creation of polymeric MEMS typically involves the use of a micro structured mold to replicate polymeric materials with the features in micron scale dimensions. Most actual techniques for micro structured mold fabrication rely on conventional semiconductor materials such as a silicon wafer and standard microlithography techniques initially developed for the microelectronics industry [1, 2]. The vertical structuring direction and very small deformation rates allow for the production of microstructures with very high aspect ratios and small inner stresses. Suitable materials are conventional thermoplastics. These materials are characterized by a wide range of properties. Plastics with a high service temperature, high chemical stability or excellent optical properties are available. Special polymers, of which only small amounts are available, may be processed for fabricating prototype components.

In this paper, a laboratory hot embossing process, which uses silicon mold insert made by UV lithography and anisotropic silicon wet etching has been applied to make patterns of micro pyramids with base width of 10 and 18.5 µm. The micro pyramid microstructures can be used in solar cell or LCD designs due to the enhanced brightness of these structures. A good replication of microstructures in films of PDMS (Polydimethylsiloxane) has been demonstrated. PDMS belongs to a group of polymeric organic silicon compounds which are commonly referred to as silicones. PDMS is the most widely used silicon-based organic polymer, and is particularly known for its unusual flow (rheologic) properties. PDMS is optically clear, and is generally considered to be inert, non-toxic and non-flammable.

Soft lithography using PDMS is receiving much attention as an alternative method of rapid replication. This polymer is not only a low-cost material but also particularly suitable for use as a mold in replica molding because it can be separated easily from the master without damaging the latter.

LABORATORY PROCESS

In Figure 1, the summarized steps of a laboratory process are presented [3]. First, standard wet silicon etching process is carried out to make micro pyramids on top of silicon mold insert. The steps include: UV light lithography on silicon dioxide layer (P.R. – PhotoResist) (a); etching of silicon dioxide layer to make the etching mask (b) and the anisotropic silicon etching and removal of the masking silicon dioxide layer (c). The hot embossing process is then followed. The wafer is used as the mold inserts to transfer fine micro pyramid shapes onto the plastic material during the hot embossing process (d). Finally, the fabrication process is completed after the demolding step (e). During the anisotropic silicon wet etching step, cavities of micro pyramid type with base width of 10 and 18.5 µm and depth of about 10 µm were performed. A good replication in PDMS films was obtained.

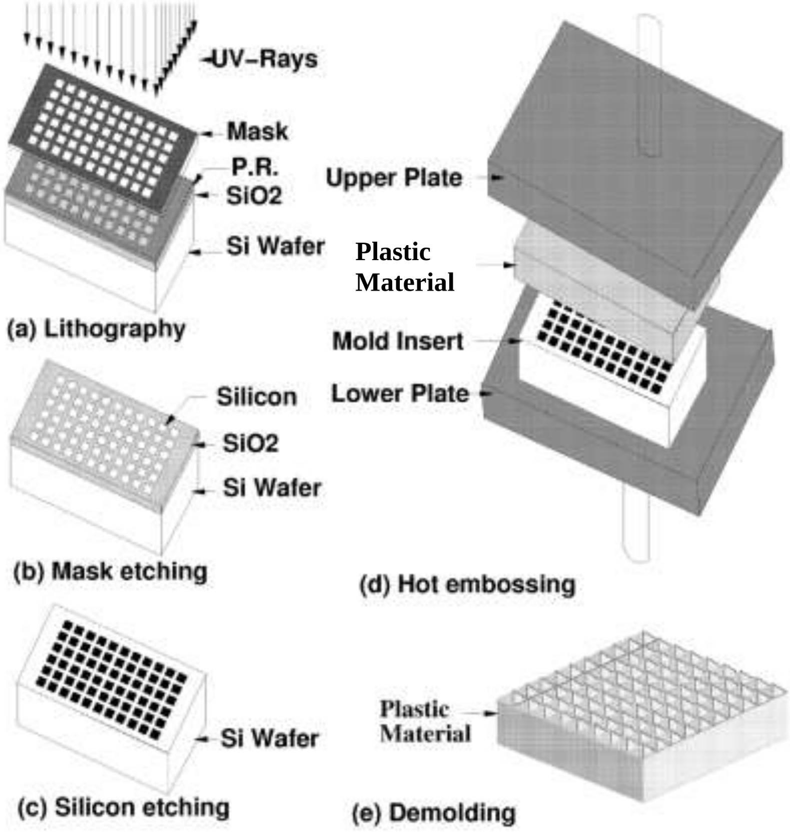


Figure 1: Fabrication sequences of a laboratory process –
(a) lithography; (b) mask etching; (c) silicon etching; (d) hot embossing; (e) demolding

MONOCRYSTALLINE SILICON MICROMACHINING (BULK MICROMACHINING)

The monocrystalline silicon micromachining allows obtaining of various shape cavities, using for this purpose the wet chemical erosion, selective, anisotropic and with shape influence by controlled doping of the processed material. *Selectivity and anisotropy* are two materials properties important for microstructures manufacturing, which means that the materials of the structural layers and the attack solutions can be "selected" so that their actions be convergent or divergent; based on the well known anisotropy of the crystalline materials, the tendency of etching adequate to the crystal orientation can be increased or reduced.

In Figure 2, one can see the correlation between an ideal selectivity and an ideal anisotropy when obtaining a certain profile characterized by a dimension "*d*" in plane and a depth "*h*". In all presented cases, selectivity of the attack substance is maximum relative to the structure material and negligible with respect to the stop layer. In case of silicon, the etch rate "*R*" is minimum for the directions <111>, some higher for the directions <110> and maximum for <100>; that is why the structure shape results trapezoidal with an angle z = 54-55°. When the layer of etching stop misses, the resulted cavity profile is that one of an inverted pyramid (the etching is self-blocked, until the planes {111} meet).

TEXTURES PERFORMING

p – (100) silicon wafers of 3 inch diameter and 375 μm thickness were thermally oxidized in wet oxygen atmosphere to obtain a silicon dioxide (SiO2) layer of about 1.7 μm thickness, used as a protective layer (mask) during etching process. The oxide layer was patterned with arrays of quadratic openings of 10 and 18.5 μm aligned along the principal flat (<110> directions) of the wafers, using a standard photolithographic technique. The silicon was then anisotropically etched in potassium hydroxide (KOH) (40 g/100 ml) at 80 °C (etch rate of about 1.25 μm/min) to a depth of about 10 μm, corresponding to an etch time of 8 minutes. The remaining oxide was removed in an HF – solution: first in "Buffered HF" solution (NH4F - HF) (6:1) at 32 °C (etch rate of about 0.1 μm/min.) and, finally, in DIP solution (HF:H2ODI) (1:10) at 25 ºC. The walls of the depressions are slowly etching {111} planes with an angle of 54.7º from the wafer surface.

HOT EMBOSSING PROCESS

The transfer process of the micro pyramid structures has performed as follows:

1. Preparing PDMS as a raw material from two components – PDMS and a strengthening agent in proportions of 10 to 1;
2. Treatment of the plastic material in a vessel connected to a vacuum pump;
3. Sputtering hydrophobic substance on the silicon mold insert;
4. Deposition of the plastic material into the silicon mold insert and keeping under pressure (established experimentally at about 0.04 N/mm^2), at 80 ^{o}C for 30 minutes;
5. Demolding structured PDMS.

After this process, the structure of micro pyramids in relief was transferred onto the plastic material (PDMS), representing the silicon wafer replica. By using the same method and the strengthen PDMS as mold insert, a polymer replica (of second generation) was obtained.

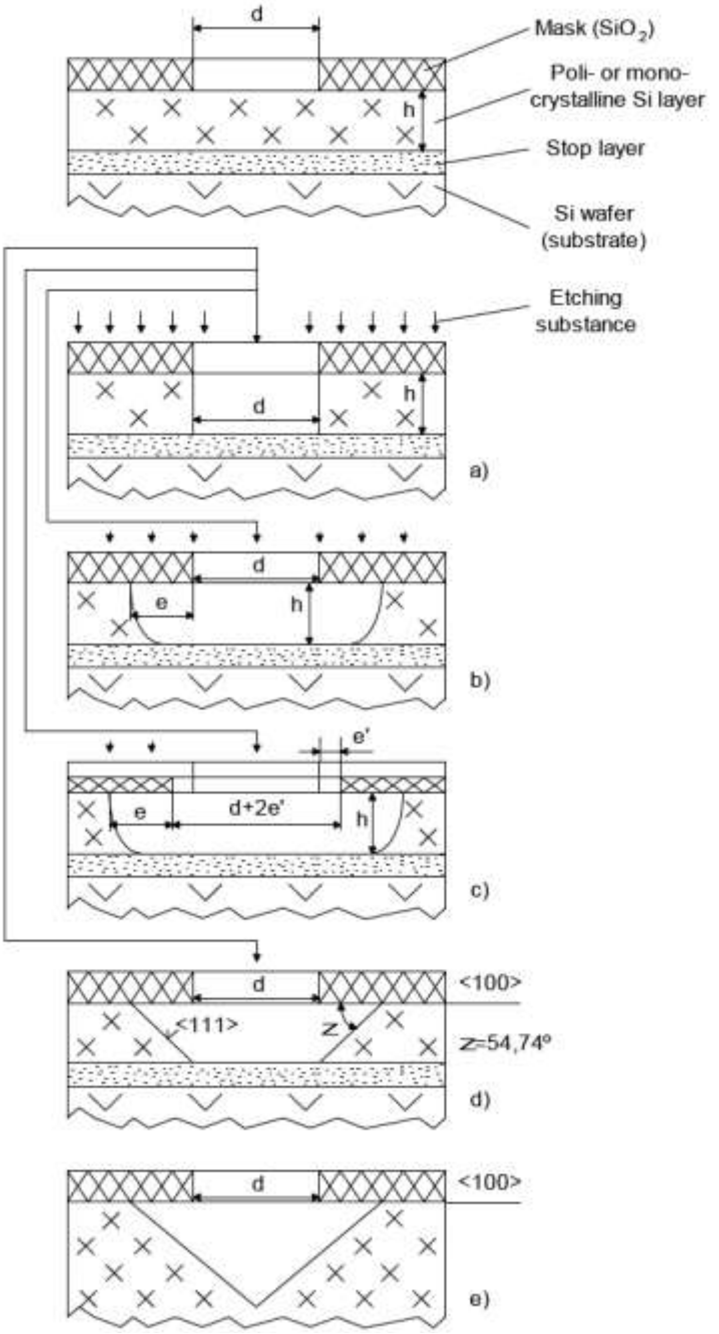


Figure 2: Result of the anisotropy and selectivity effects for a chemical etching process - a – maximum selectivity; b – isotropic etching in conditions of maximum selectivity; c – isotropic etching combined with reduced selectivity; d – anisotropic etching with maximum selectivity and etching depth limitation by a stop layer; e - anisotropic etching with etching depth limitation by the dimension "d" in plan of the mask; < > is a noting of the totality of equivalent directions in the crystal

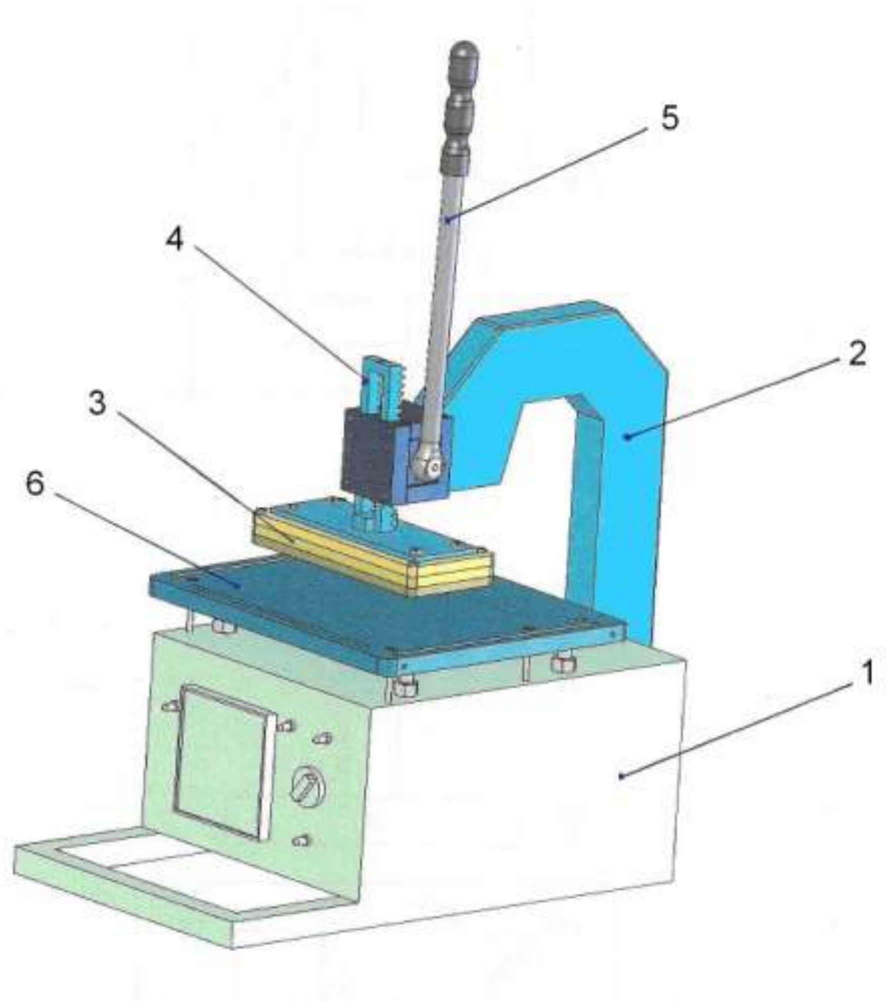


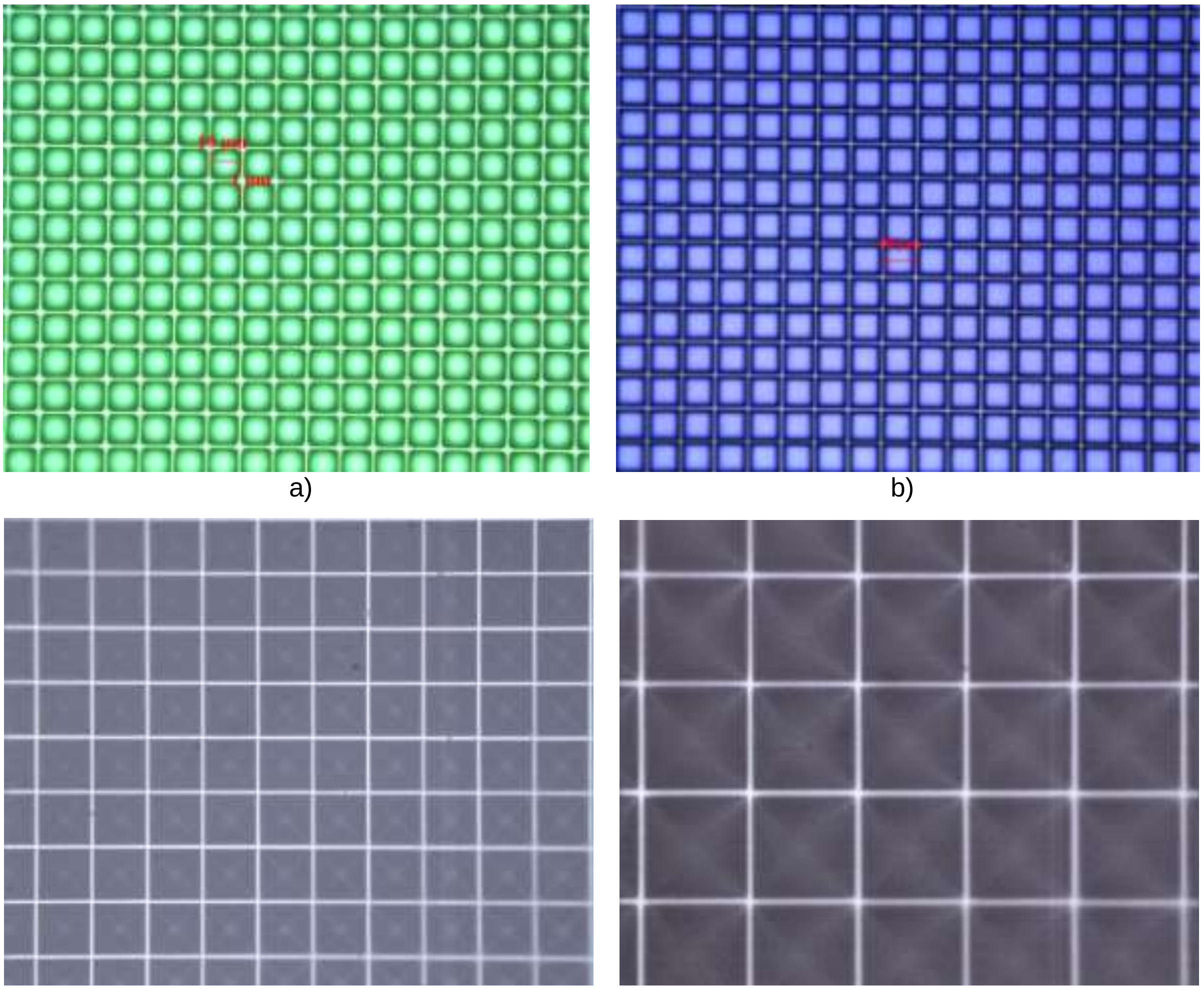
Figure 3: Drawing of device used in the hot embossing process – 1 - carcass (in the carcass there are a temperature regulator, a contactor and a timer), 2 - cantilever, 3 - platen heated with an electrical resistance, 4 - mechanism for the vertical movement, 5 - manipulated arm, 6 - working table

RESULTS AND CONCLUSIONS

The patterns include squares placed in a rectangular grid. In Figures 4 and 5, images of the fabricated microstructures, viewed at an optical microscope, are presented.

Figure 4: a) and b) – cavities of inverted pyramids with base width of 10 µm on top of silicon wafers after etching in KOH solution (self-blocking etching); c) and d) – replication of these structures (micro pyramids with tip in upper part) onto PDMS during the hot embossing process.

Figure 5: a) and b) – cavities of inverted frustums of pyramids with base width of 18.5 µm on top of silicon wafers after etching in KOH solution (etching of limited depth); c) and d) – replication of these structures (micro frustums of pyramids with tip in upper part) onto PDMS.



a) b)

c) d)

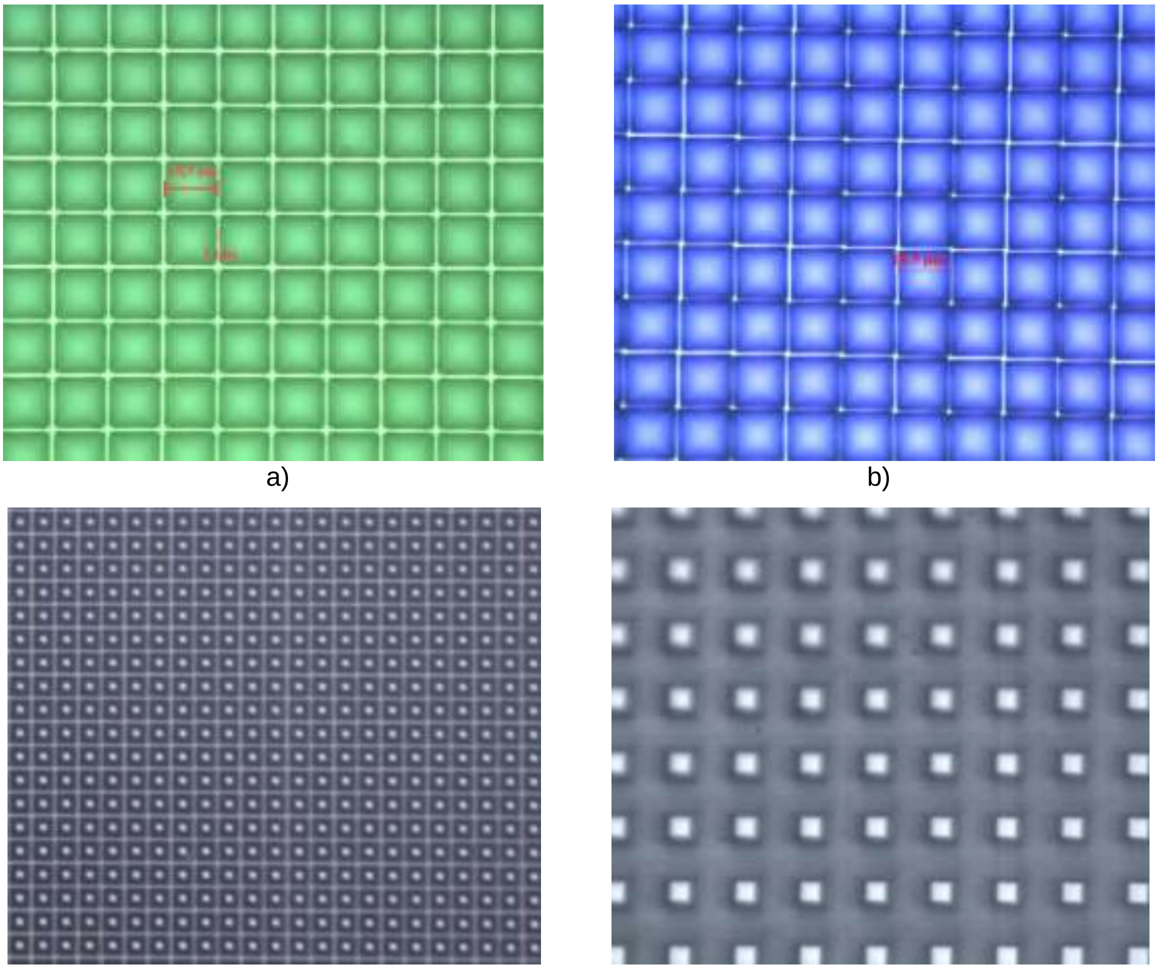
Figure 4: Photos showing micro pyramid type structures of 10 µm – a) Si wafer protected by SiO_2 mask, b) Si wafer after SiO_2 mask removing, c) and d) micro pyramids trasferred onto plastic material (PDMS)

The surface roughness measured on wafers was Rz=0.07...0.1 µm between the structures. In cavities Rz=0.06…0.02 µm (the smaller value for KOH 25 % at 80 °C with IPA/ isopropylic alcohol addition).

Hot embossed microstructures on PDMS (Polydimethylsiloxane) films have been successfully fabricated under a laboratory process. The method uses anisotropically wet etched silicon as mold insert.

Hot embossing is a very versatile replication method. Electroplated nickel as mold insert, double-sided molding and positioned embossing on pre-structured substrates will be investigated in the future developments.

Various materials (PDMS, PMMA, PVC and so on) with varying properties can be used, opening a variety of applications in microoptics, microfluidics, micromechanics, medical engineering and multi-scale systems.



a) b) c) d)

Figure 5: Photos showing micro pyramid type structures of 18.5 µm – a) Si wafer protected by SiO_2 mask, b) Si wafer after SiO_2 mask removing, c) and d) micro frustums of pyramids trasferred onto plastic material (PDMS)

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