研究解説

Microstructures and Microfabrication using Thick Photo Resist

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1. Introduction

Recently, advanced MEMS technology from the developments in electronics has given rise to the advent of various microfabrication techniques to create new microstructures from various materials. Specially, high aspect ratio structures (HARS) or needs for building three-dimensional micro devices have been demanded for a wide variety of applications.

Several approaches to achieve such requirements have been reported. Not only have we achieved deep structures with high aspect ratios by plane lithography, but also managed to sculpture freely in space with certain methods or in certain atmospheres [1]. It is the objective of this note to describe the micro fabrications of HARS mainly used thick photo resist.

Before going into micro fabrication process with thick photo resist, it should be mentioned here that lots of methods for complete 3D microstructures have been studied in various ways. Three-dimensional processes for fabrication of polysilicon microstructures [2] and single-crystal silicon microstructures [3] have been previously presented. Other way to produce simultaneously tens to hundreds of micrometers thick electrically isolated poly and single-crystal silicon microstructures was also developed [4] (deep reactive ion etching, DRIE). RIE of polyimide has been presented as a method to fabricate high aspect-ratio structures [5]. Alternatively, ICP-RIE (Inductively coupled Plasma reactive ion etching) process is proposed to fabricate multiple height HARS [6], [7]. However, dry etching technique is still considered exclusive. In the other hands, surface micromachined polysilicon structures are also prosperous for the building three-dimensional micro devices using microhinges [8], [9] and advanced 3D self-assembling technique [10].

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Other suggested methods are conventional machining adapted to microstructures, such as micro-milling [11], micro-EDM and WEDG (wire electro-discharge grinding) [12], the lost molding process [13] and direct writing tools like rapid prototyping [14], the micro-stereolithography [15], laser chemical vapour deposition [16], the focused ion beam technique [17], etc.

2. Microfabrication using High-aspect-ratio photolithography

High aspect ratio lithography on thick resist (>50 μm) adds a new dimension and flexibility in the fabrication of tall and HARS for micromachining and packaging applications. Several methods have been used to fabricate molds for plated metal microstructures [18].

The LIGA (Lithographie, Galvano-formung, Abformung) process [19], which is the most prominent of these techniques, has been developed to form very tall (up to 1mm) structures without sacrificing the accuracy of the lateral dimension. The thick film of PMMA is patterned using a synchrotron X-ray source. The PMMA template is used to electroform metal microstructures.

Since this is an expensive, time-consuming process with limited exposure tool availability, it gave birth to the 'poor man's LIGA where thick resist is exposed to standard UV light. Recently several authors have reported on the use of negative photosensitive printed wiring board resists and polyimide [20] and positive diazo-type photoresists [21], [22], [23]. N.F. de Rooij *et al.* presented the positive thick photoresist moulds fabricated for nickel high-aspect-ratio microstructures [24]. The figure 1 shows one of result of 80 μm thick comb-like resist mould structure.

However, it remains generally difficult to achieve high-aspect-ratio patterns because of the resolution limitations, the high optical absorption and the limit of spin-coat thickness of resist systems. Therefore, a new resist system for high aspect-ratio's MEMS application are required to have several critical properties:

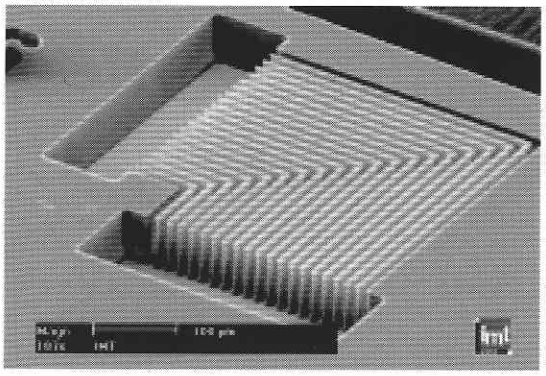

Fig 1. 80 μm thick line and space mould by thick positive resist patterns [24].

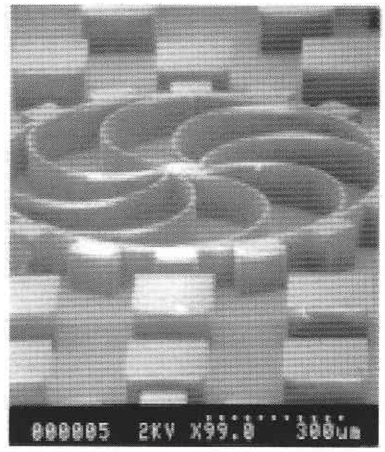

Fig 2. SU-8 microstructures by one single spin-process.

a low optical absorption, easy to spin to thick layers, high resolution and sensitivity, thermal stability, and chemical resistance. Therefore, a new resist called SU-8 has been announced attractive to fulfill the above profiles [25], [26].

3. SU-8: low cost negative resist for MEMS

The SU-8, which was originally developed by IBM and EPFL, is a negative, epoxy-type, near-UV photoresist (365 nm). It consists of a multi-functional, highly branched polymeric epoxy resin (at Shell Chemicals, called EPON SU8) dissolved in an organic solvent (gamma-Butyrolactone), along with a photoacid generator. This photoresist can be as thick as 2 mm and aspect ratios up to 25 have been demonstrated with a standard UV-lithography, thereby reducing costs and increasing throughout.

Therefore, SU-8 has enabled the development of many new MEMS devices that were previously not possible using other photoresist materials. Some of these applications include micro-fluidics, micro chemical analysis device, ink jet nozzles, micro-molds and LIGA-type processes, etc [27], [28], [29], [30].

The main interest feature of the resist includes the possibility to define high aspect ratio microstructures at low-cost by simple lithography, as shown in Figure 2. Figure 2 shows the test microstructures made with SU-8 of 150 μm-thick layers with 12:1 aspect ratio. In the other hands, other interest for optical MEMS applications is that SU-8 is transparent with a refractive index of 1.8 as shown by Arscott *et al* [31].

We introduce here one optical MEMS application using photoplastic SU-8 material as low-cost and rapid fabricated microstructures. Besides the following application result, authors have developed the application of shadow mask membranes that are directly fabricated from photoplastic SU-8 by simple lithography [32]. The presented method provides a rapid and low-cost approach for unconventional patterning of surface patterns on micron scale without lithography. Simple photoplastic process produces the mechanical masks as microstructures.

4. Photoplastic SU-8 probes for near-field optical applications [33]

Scanning Near-field Optical Microscopy (SNOM) overcomes the diffraction limit of resolution, and has hence become a widely used technique for the optical investigation of materials in sub-wavelength range. Moreover, it can also be used to induce molecular rearrangements, single molecule detection and near-field optical data storage. However, the inexpensive mass-fabrication of high-quality probes for ultra-high resolution near-field optical applications is still unsolved albite several methods for integrated manufacturing have been proposed in the past.

As a possible remedy to this limitation we developed a new wafer-scale microfabrication process for sharp pyramidal and bright photo-plastic (SU-8) probes. The microfabrication process is adapted from a novel technique to make low-cost photoplastic atomic force microscope (AFM) probes developed by IBM [34]. The probes are fabricated of a transparent SU-8, which allows simple batch fabrication based on spin coating and subsequent near-ultraviolet exposure and development steps. This advantage is used here to define a sharp and high aspect ratio probe dedicated for near-field optical applications.

The process starts with the fabrication of molds in a <100> oriented silicon wafer by using the anisotropic etchant potassium-hydroxide. This self-limiting process results in inverted sharp pyramids limited by four <111> silicon crystal planes. The cone angle is in the order of ~ 54°. After the mold is covered with a ultra-thin de-adhesion layer (self-assembled monolayer) and with a thin (<100 nm) evaporated metal film, two layers of SU-8 are conformally spin-coated (5 μm and 200 μm), exposed and developed to form a cup into which the optical fiber is micro-assembled and glued. Finally, the transparent nanoprobe is lifted-off the mold with the Al coating as shown in Figure 4. The aperture is formed using a focused ion beam (FIB) technique. The major asset of this process is the smooth Al layer, allowing the aperture of the nanoprobe to be approached to the surface within a few nanometers.

Figure 3 shows the fabrication process for the proposed SNOM probe using micromachining technology. The schematic figure and SEM image of the fabricated probe is shown in Figure 4. Far field-measurements of probe throughput efficiency are typically ~ 10^{-4} for an aperture of 80 nm. This confirms that our pyramidal probes are indeed very bright and are suitable for NSOM applications. We have obtained topographic images using a tuning fork based shear force distance control set-up and near-field fluorescence images of single molecules embedded in PMMA.

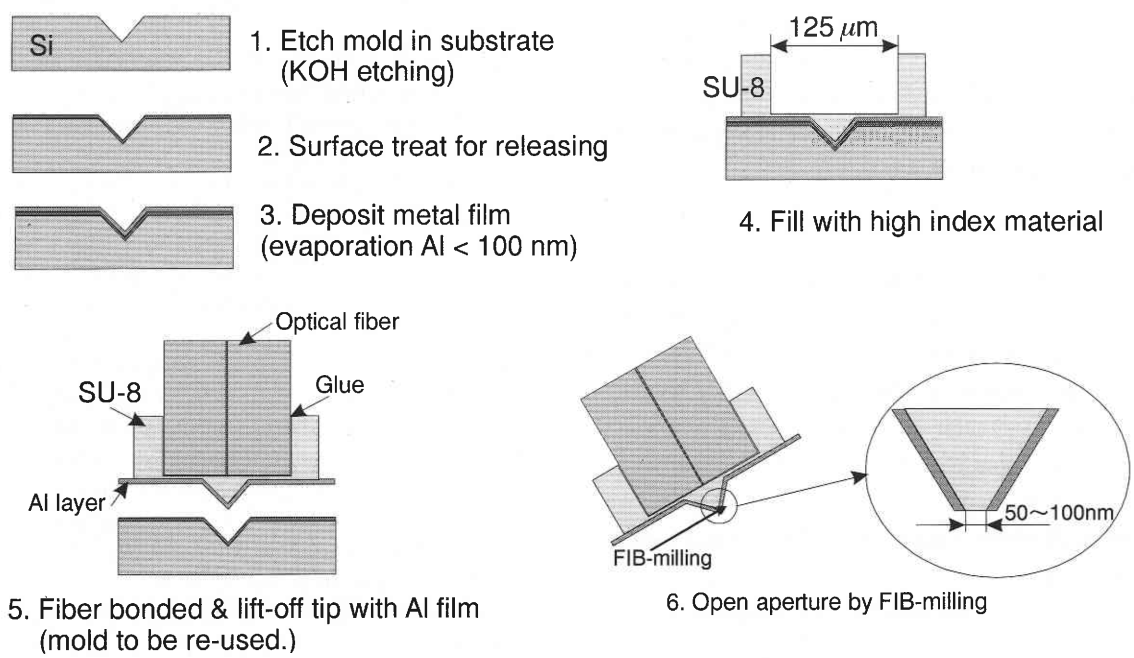

Fig 3. The process chart of SU-8 SNOM probe [33].

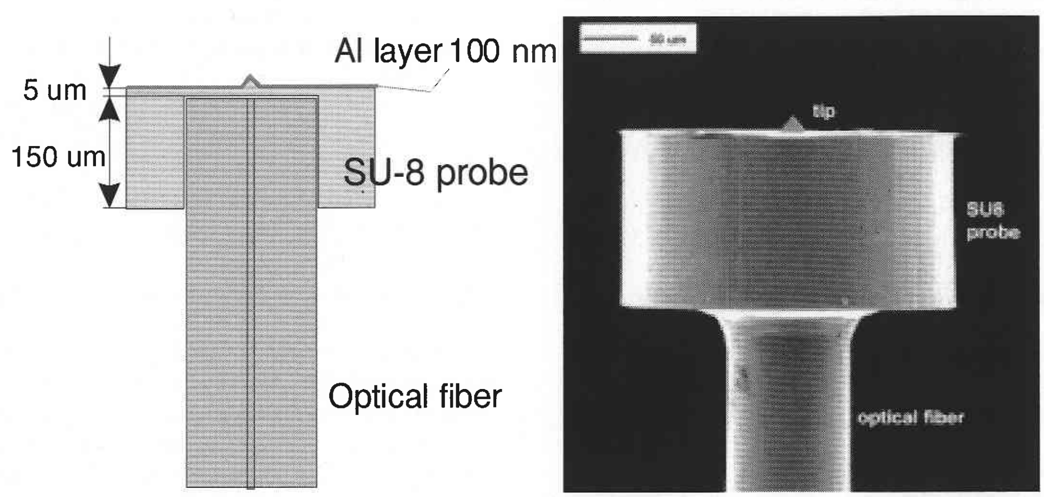

Fig 4. Schematic (left) and SEM micrograph (right) of photoplastic SNOM probe [33].

5. Conclusions

We begin with brief overview of microfabrication methods for high-aspect-ratio structures and in more detail describe some SU-8 microstructures for MEMS applications. Not only as micromold structures but also as the master or as micro structural material, the photoplastic thick resist is very promising for various future MEMS/NEMS applications. Owing to high (relatively) thermal stability, chemical resistance and a good biocompatibility, microfabrications using thick polymer resists are expected to be widespread.

Finally, this paper described a new type of SNOM probes made of a transparent sharp pyramid that is microfabricated by a simple molding process based on spin coating of a photoplastic epoxy resist. The simple molding and replication techniques shows interesting potential for the micro-fabrication of low-cost, large volume photoplastic microstructures.

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