Patterning of CVD Diamond Films For MEMS Application

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ABSTRACT

To apply diamond films in microelectromechanical systems (MEMS), it is necessary to develop the patterning technologies of diamond films in the micrometer scale. In this paper, three different kinds of technologies for patterning CVD diamond films carried out by us were demonstrated: selective growth by improved diamond nucleation in DC bias-enhanced microwave plasma chemical vapor deposition (MPCVD) system, selective growth of seeding using diamond-particle-mixed photoresist, and selective etching of oxygen ion beam using Al as the mask. It was shown that high selectivity and precise patterns had been achieved, and all the processes were compatible with IC process.

INTRODUCTION

The unique properties of diamond present intriguing possibilities for the fabrication of diamond film microelectronic devices and microelectromechanical systems (MEMS), including micro-sensors and micro-actuators, which might benefit by extended dynamic range, fast response, reduced wear and good resistance at higher temperature. Patterning diamond films is one of the basic processes of fabricating these devices. However, traditional lithography technique to pattern diamond was almost impossible due to its extreme resistance to chemical solution. Selective growth, plasma etching and laser etching were the alternative methods and have been developed in the past years. The selective methods suggested in [1,2] involved nucleation pretreatment of the substrates by scratching or seeding and nucleation suppression of undesired region by the mask, fabricated before scratching and then etching away or deposited after scratching, or simply reactive etching the scratching layer, but the nucleation selectivity (nucleation ratio of desired to undesired regions) is lower. Using plasma etching diamond films[3], the etching rate was relatively low and etching selectivity of mask materials and diamond films was very poor. Laser etching could achieve a relatively high etch rate[4], but the special instruments were needed and the precise diamond patterns for MEMS were difficult to be constructed. In this paper, we report three different kinds of technologies for patterning diamond films, which had been developed in our laboratory and already used in the fabrication of diamond film microstructures.

EXPERIMENTS

1. Selective growth of polycrystalline diamond thin films using bias-enhanced chemical vapor deposition (MPCVD)

The detailed information about MPCVD system and experimental conditions for DC bias-enhanced MPCVD nucleation and normal growth had been published in [5], and only a brief description demonstrates here.

The fabrication process of selective growth of diamond films using bias-enhanced MPCVD is schematically shown in Fig. 1. First, silicon wafers were cleaned by conventional RCA process, and thermally oxidized at 1180°C for 120 min to attain a SiO_2 layer of 1 μm. The SiO_2 layer was lithographically patterned and chemically etched in buffered HF solution to form the desired patterns. Then, the silicon wafers with patterned SiO_2 masks were treated for nucleation using the DC bias-enhanced MPCVD system. Slightly etching the SiO_2 mask was employed to remove the diamond nucleus particles on SiO_2 mask surface, but the diamond nucleation density on Si regions was not reduced. Normal growth of diamond films was carried out in the MPCVD system without applying DC bias. Finally, the buffered HF solution was used again to etch away the remainder SiO_2 mask on as-grown wafers. Thus, fine diamond patterns with smooth surface, steep sidewall and small gap were obtained.

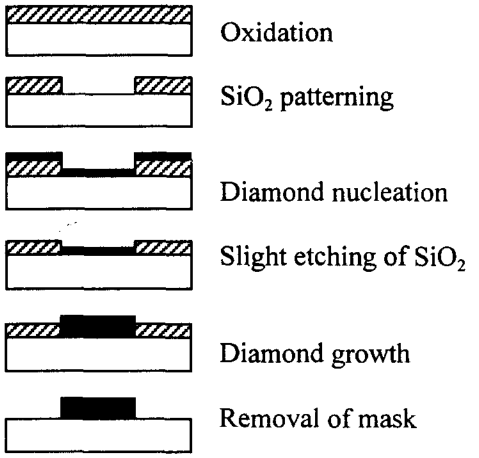

Fig. 1. The process of selective growth of diamond films using bias-enhanced MPCVD

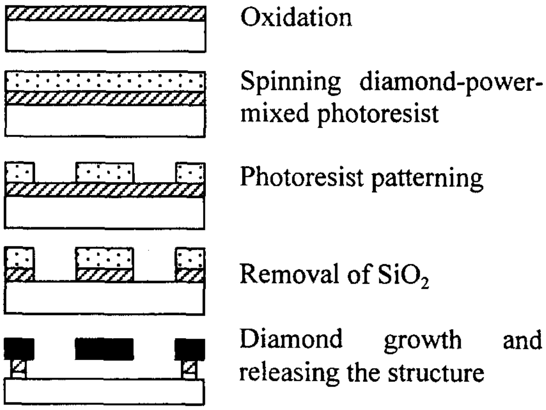

Fig. 2 The process of selective growth of diamond films using photoresist mixed with fine diamond power

2. Selective growth of polycrystalline diamond thin films using photoresist mixed with fine diamond powder

The selective growth of diamond films using diamond particle mixed photoresist was similar to the method proposed by Aslam and Tamor[6]. The process is schematically shown in Fig. 2. First, fine diamond powder with particle size of 0.5μm was mixed with positive photoresist (AZ1350) and suspended by ultrasonic agitation for 20 min to achieve a homogenous mixture. The mixture was spun on the thermally grown SiO_2/Si substrate. After baking, conventional UV exposure was employed to pattern the coating layers, which would be used as crystal seeds in the diamond selective growth. The residual diamond particles grown on the exposed SiO_2 surface were removed with buffered HF solution, and selectively grown diamond patterns were obtained. At last, a time-controlled etch, using HNO_3:HF (3:1) solution to isotropically etch the Si substrate, was applied to free the selectively grown diamond structures from substrates except for the anchor regions.

3. Oxygen ion beam selective etching of continuous diamond films

The selective etching of continuous diamond films by oxygen ion beam with Al as a mask has been carried out and will be published in greater detail soon. Continuous diamond films were directly grown on poly-Si/SiO_2/Si substrates in hot-filament CVD system. Al mask layer with thickness from 0.2 to 0.8μm, depended on the thickness of diamond films, was deposited and patterned by standard photolithography. Then, the specimen was etched in reactive ion beam etching system using pure oxygen as reactive gas source.

RESULTS

Fig. 3 shows the structure of diamond film micromotor, selectively grown by DC bias-enhanced MPCVD technology, with the rotor diameter of 150um, thickness of 2.0μm, the gaps of 1.6μm and 3.0μm between rotor and bearing, rotor and stator, respectively. The selectivity about 5×10^6 has been obtained, which is one order greater than those obtained in previous works[7].

Fig. 4 shows a SEM micrograph of typical diamond linear micro-resonator, selectively grown by diamond particle mixed photoresist technology, with the thickness of 2.2 μm, beam length of 120μm , beam width of 5.0μm and gap of 1.8μm between fingers. It is also shown that the comb-like fingers and beams have been suspended above the substrate with the clearance about 1.6μm.

The obtained etch rates of Al mask and diamond films were 0.8nm/min and 33nm/min, respectively. Thus, good etching selectivity of about 40 between the Al mask and the diamond films was obtained. A SEM photograph of ion beam etched diamond microstructure with the thickness of 3μm and steep sidewalls is shown in Fig. 5. The suspended diamond film microstructures can also be seen from the photograph.

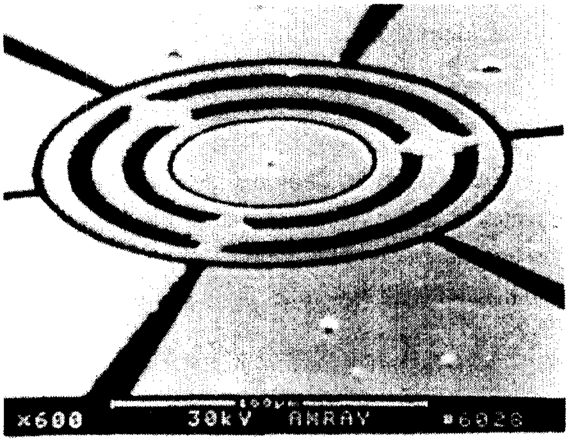

Fig. 3 SEM micrograph of the structure of diamond film micromotor, fabricated by selective growth using bias-enhanced MPCVD

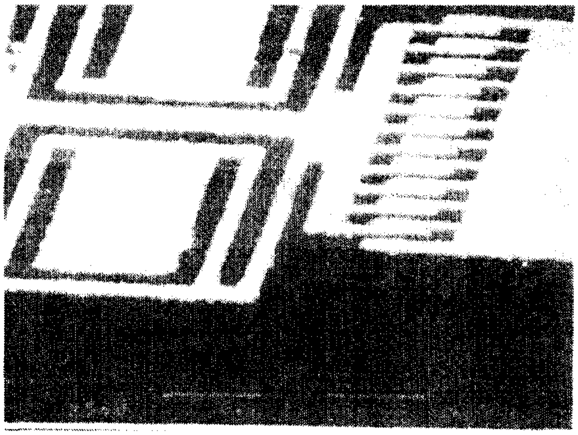

Fig. 4 SEM micrograph of typical diamond linear microresonator, fabricated by selective growth using photoresist mixed with fine diamond power

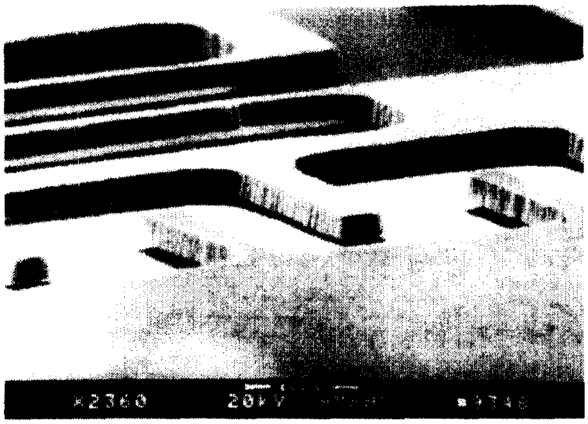

Fig 5 SEM micrograph of ion beam etched diamond film microstructure

DISCUSSIONS

Our experiments have embodied our efforts to put the patterned diamond films for practical MEMS application. The results had shown that the above-mentioned patterning technologies are possible to form diamond film patterns with dimension of a few micrometers and gaps of 1-2μm. Thus, these technologies for patterning diamond films combined with other related technologies, such as sacrificial layer, Si bulk micromachining technologies and etc., will be useful for some microfabricated diamond or diamond film coated devices used in harsh environment, in which Si and alloy material cannot satisfy the demand. However, the choice of a particular technology for an actual application primarily depends upon the substrate materials and the device processes.

Silicon substrate must be adopted in the first selective growth technology, because only the diamond nucleation with high density ($10^{11}cm^{-2}$) can be introduced on Si by DC bias-enhanced MPCVD. The second selective growth technology has no restrict on the substrate materials although Si has been used as the substrate in this experiment. Because very fine diamond powder mixed in photoresist as crystal seeds was not yet obtained commercially, the surface of the diamond microstructure was relatively rough. However, the process is simple and compatible with IC process. Especially, diamond microstructures released by etching Si substrate has been fabricated by us for the first time. The dry etching method can directly obtain diamond films patterns on any diamond-coated substrates. In our experiment, O_2 was adopted as reactive gas, which is cheaper and safer than Xe and NO_2 reported in previous works, and the patterned film has steeper sidewalls than previous etching results[3,8].

SUMMARY

Three technologies for patterning CVD diamond films have been demonstrated, which are all compatible with IC process. High selectivity and precise patterns can be realized for selective growth and dry etching of diamond films, respectively. In addition, an appropriate combination of these technologies can realize diamond film microstructures in three dimensions leading to many novel applications not only for MEMS.

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