Study on the applications of SiC thin films to MEMS techniques through a fabrication process of cantilevers


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Abstract

We have tried to find the most suitable conditions for the deposition process of silicon carbide thin films as a material for MEMS techniques. We have also studied its application to semiconductor processes. To do this, we have tried to fabricate several dimensions of cantilevers with these silicon carbide thin films. High quality silicon carbide thin films are grown by metal-organic chemical vapor deposition (MOCVD). This process employs single molecular precursors such as diethylmethylsilane (DEMS), 1,3-disilabutane (DSB) at a pressure of $1 \times 10^{-3}$ Pa and a growth temperature in the range of 700–1000 °C. Two fabrication methods are tested for initial fabrication of cantilevers. First, deposit SiC thin films on Si based atomic force microscopy (AFM) cantilevers. Second, used the lift-off process. To get three-dimensional cantilever-shaped SiC thin films, moreover, we chemically etched silicon substrate with strong alkaline solution such as TMAH at 80 °C. In addition, a high resolution of probe tips on the cantilevers was achieved using electron-beam deposition in a carbon atmosphere.

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1. Introduction

Micro electro mechanical system (MEMS) technology is used for various sensors, adjustors and navigation devices, etc. It is a super fine technology that applies a structure composite system of micro size and specially synthetic knowledge of electricity, electromagnetism, machinery, chemistry, etc. is a required composition technology. Utilizing as it is a semiconductor manufacturing technology and is progressing research from each place actively because application is infinite. It is advanced in integrated form that the beginning sensor in 1970s produced micro machinery structure in 1980s logic circuit and actuator reaches in 1990s. In MEMS technology, miniaturization, high efficiency, multi-function, and integration are available and improve stability and reliability through ultra-precision fine processing. Also, assembly necessity reduces by possible of embodied intergration system and there is advantage that can do mass produce cheaply because it is manufactured in bundle process.

Since its invention by Binnig, Quate, and Gerber in 1986, atomic force microscopy (AFM) is a powerful tool for high resolution imaging of surfaces. But, the speed of imaging is slow, and measurement of regions that slant such as narrow and deep valleys is impossible or difficult because the probe has limited size and shape, and error of measurement occurs because of the distortion phenomenon (convolution effect) by the probe shape [1]. Today MEMS techniques are used to mass produce well defined cantilevers with dimensions on the order of 100 µm. In the AFM, cantilevers must satisfy the following conditions to be very important element that decide resolution and gets high resolution: (1) low spring constant; (2) high resonant frequency; (3) radius of curvature is small and sharp tip; and (4) small opening angle [1–3]. Decreasing cantilever’s dimension to the order of micrometers gives much higher resonant frequencies than larger cantilevers, while simultaneously providing the same spring constants. Thus small cantilevers should allow for faster measurements.

It is already known that SiC thin film has excellent chemical, mechanical and electronic properties [8,9]. In spite of these merits, dry etching has been the sole method of production and studied frequently as patterning methods because of its high bonding energy and chemical inertness [10–12]. Inductively coupled plasma (ICP) etching technology enables to get high plasma density and control its bias voltage as high quality anisotropy etching and fast etching speeds are possible. So it is used broadly. But, by far, the applications of SiC thin films for the semiconductor process and MEMS technology have not developed markedly.

In this study, we tried to get high quality SiC thin film useful for MEMS applications by using diethylmethylsilane (DEMS), 1,3-disilabutane (DSB) for its precursors. And we are now trying SiC cantilever manipulation by applying established cantilever manufacturing techniques for high performance cantilever manipulation as well as the possibility of SiC thin film for the MEMS.

2. Experimental

According to the theory mentioned above, we can gain more high resonant frequency as the dimension of a cantilever becomes smaller [4–7]. But unconditional reduction of dimension can bring increase the high spring constant to more than that of the resonant frequency. In this experiment, we tried manipulation of the cantilever which has the same width and thickness and different length, for comparison of the resonant frequency versus the rectangular shape cantilever. Because a pyramidal tip might be heavy and large in a relatively small cantilever, carbon tip growth by e-beam deposition is useful and we apply this method to overcome these
problems. It is also useful to reduce the number of masks and processes. So, in this case, we experiment with carbon tip growth on the Si cantilever by e-beam direct induction. Using TEM spot mode, fixed time e-beam induction made growth of the carbon cantilever after arranging the Si cantilever and the e-beam vertically in residual gas conditions of a diffusion oil pump.

For initial fabrication of the cantilevers, we used two fabrication methods and compared them. The first is to deposit SiC thin films on single crystalline Si based atomic force microscopy (AFM) cantilevers (NSC12 series of tipless cantilevers in MikroMasch). The second is to use the lift-off process; SiC thin films are deposited on patterned oxide thin films, which are then treated with HF solution. To get three-dimensional cantilever-shaped SiC thin films, we chemically etched silicon substrate with a strong alkaline solution such as TMAH at 80 °C. The chemical stability of SiC thin films was inspected through SEM images. Finally, a high resolution of probe tips on the cantilevers was achieved using electron-beam deposition in a carbon atmosphere.

To grow high quality SiC thin films, we utilized the MOCVD method. DEMS and DSB were used as single molecular precursors without carrier and bubbler gas. A Si(100) wafer was used as substrate and it is cleaned by a chemical method reported previously. The general deposition condition was a working pressure of $10^{-3}$ Pa and growth temperature in the range of 700—1000 °C. The detailed experimental process of SiC thin film deposition was reported elsewhere [15,16].

A number of analysis and characterization techniques are employed to investigate the deposited SiC films. These include energy dispersive X-ray spectroscopy (EDX) to confirm chemical composition, scanning electron microscopy (SEM) to investigate the SiC film morphology, and atomic force microscopy (AFM) to investigate SiC film topology.

![SEM images of SiC thin films grown on Si(100) substrates using DEMS at various deposition temperatures.](image)

Fig. 1.
3. Results and discussion

SEM images of SiC thin film morphology using DEMS at variable temperatures are shown in Fig. 1. In Fig. 1(a), SiC films have thin and smooth surfaces and consist of nanosize crystals. With increasing the deposition temperature to 900 °C or 1000 °C, relatively larger crystals can be seen as in Fig. 1(c) and (d). This means that at deposition temperatures over 800 °C, crystal sizes and crystallinity of SiC thin films are dependent on substrate temperature. The main shape of the crystal at 900 °C is square and the most high quality SiC film can thus be obtained at between 900 and 950 °C. But the film has a relatively rougher surface than that grown below 800 °C.

Fig. 2 shows SEM images of SiC thin films grown using DSB at variable temperatures. SiC thin films grown over 900 °C have thick (for example, 1.5 μm at 950 °C) and rough surfaces. This means that SiC thin film using DSB is not suitable for growing e-beam deposition tips despite good growth rate because of its rough surface. So we firstly deposit SiC thin films at 800 °C for obtaining a smoother surface than that at higher temperatures. From these two step processes, we could obtain very smooth film as shown in Fig. 3(a). The RMS roughness of the SiC films grown at 800 and 950 °C is approximately 37 nm. Fig. 3(b) shows the X-ray diffraction patterns of SiC thin films grown on Si(100) using DEMS and DSB precursors. The XRD pattern of SiC thin film grown using DEMS at 900 °C and DSB at 950 °C exhibit intense and sharp peaks at the (200) reflection. This indicates that crystalline 3C–SiC film can be deposited and this is in good agreement with the SEM result shown in Figs. 1 and 2.
Fig. 4 shows a SEM image of a cantilever covered with SiC film. In addition, nanowire is also observed on the cantilever. The detected Al signals in EDX spectra come from the Al mask in patterning. In general, AFM cantilevers are made by the etching method using the Al mask. So we suppose that Al contaminant on the cantilevers acted as a metal catalyst for the growth of SiC nanowires.

Carbon tip growth by e-beam deposition as shown in Fig. 5 was also tried to gain a sharp tip without pyramidal tip formation. Cantilever fabrication using CNT is investigated to deal with the measurement problems of a deep trench structure. But it has some defects because it is so complicated and its productivity is reduced too much. In spite of using a fine cantilever like CNT, it is impossible to get information on the trench wall that is nearly vertical. If we can grow very thin and long ball type carbon tips, it may have some merits that aspect ratio is not downsizing than case of CNT attached and a ball type tip can be made to measure the trench wall more easily.

By e-beam deposition, therefore, it is possible to grow the carbon tip of various aspect ratios under the controlling variables of the e-beam, such as induction time, acceleration voltage, and e-beam probe current, etc., regardless of varied geometrical morphology of Si cantilever as substrate. Especially, the technique enable to grow high aspect ratio carbon tip can apply to reduce the troubles of fabrication of high speed measurement AFM cantilever integrated PZT film driver.

In Fig. 5, SEM images are displayed showing the growth behavior of EBD tips at diffusion pump oil atmosphere as a function of the electron beam acceleration voltage and probe current.
It was predicted that the deposition of carbohydrates, oxygen, carbon monoxide and water, etc., known as residual gas in chamber resulted in a format of carbon tips after thermal decomposition by e-beam. The optimal conditions for high aspect ratio tip growth is low probe current, high acceleration voltage and proper exposure time. The maximum height of the tips is less than 1 μm. From Fig. 5, we realized that with increasing acceleration voltage and probe current the height of the carbon tips as well as the base diameter are also increased simultaneously. Some methods are still required to enhance the height of the tips [13,14].

4. Conclusions

Thin films of high quality silicon carbide have been produced by high vacuum metal-organic chemical vapor deposition (MOCVD) using diethylmethylsilane (DEMS), 1,3-disilabutane (DSB) single molecular precursors at temperatures in the range 700–1000 °C and pressure 1 × 10⁻³ Pa for MEMS applications.

The amorphous carbon tip was grown by direct electron-beam deposition method. The height and base diameter of the tip can be controlled by varying the acceleration voltage and probe current of the electron beam.

![Fig. 4. SEM images of SiC thin films and nanowires deposited on small rectangular cantilevers.](image)

![Fig. 5. (a) Carbon tip image with fixed acceleration voltage and variable beam probe currents. (b) Carbon tip image with fixed beam probe current and variable acceleration voltages.](image)
Application of SiC thin film, which is famous for its superior intrinsic properties, to the MEMS technique has also been tried in this paper. It is expected that SiC cantilevers have much higher resonant frequency than conventional cantilevers and that it proves to be a promising method for application of SiC thin films to MEMS.

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References