압전 MEMS 스위치 구현을 위한 DLC 구조층에 관한 연구

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DLC Structure Layer for Piezoelectric MEMS Switch

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요 약

본 논문에서는 d33 모드로 구동하여 우수한 성능을 가지는 RF-MEMS 스위치의 구현을 위한 희생층과 구조층의 조합으로서 DLC와 포토레지스트를 제안하였다. 포토레지스트의 경화현상을 방지하기 위하여 DLC 구조층은 상온에서 RF-PECVD 방법을 이용하여 증착하였다. 그리고 PZT 압전층은 RF 마그네트론 스퍼터링 방법을 이용하여 상온에서 구조층 위에 증착하였으며, 희생층의 제거 후 결정화를 위하여 급속 열처리 (RTA) 장비를 이용하여 후 열처리하였다. PZT의 결정화 과정과 DLC의 기계적 성질의 변화를 다양한 온도조건에 따라 분석한 결과 DLC는 PZT의 결정화 온도까지 영률과 강도면에서 우수한 특성을 나타냄을 확인하였다. 또한 포토레지스트를 사용함으로서 공정을 단순화하고 낮은 비용으로 제작이 가능하였다.

Key Words : diamond like carbon (DLC), structure layer, piezoelectric, MEMS, switch

ABSTRACT

In this paper, a new set of structural and sacrificial material that is diamond like carbon (DLC)/photoresist for high performance piezoelectric RF-MEMS switches which are actuated in d_{33} mode is suggested. To avoid curing problem of photoresist sacrificial layer, DLC structure layer is deposited at room temperature by radio frequency plasma enhanced chemical vapor deposition (RF-PECVD) method. And lead zirconate titanate (PZT) piezoelectric layer is deposited on structure layer directly at room temperature by rf magnetron sputtering system and crystallized by rapid thermal annealing (RTA) equipment. Particular attention is paid to the annealing of PZT film in order to crystallize into perovskite and the variation of mechanical properties of DLC layer as a function of annealing temperature. The DLC layer shows good performance for structure layer in aspect to Young' s modulus and hardness. The fabrication becomes much simpler and cheaper with use of a photoresist.

I. Introduction

For Radio frequency microelectromechanical system (RF-MEMS) switches offer great potential benefits over PIN diodes and transistor switches in aspect to low insertion loss, highisolation, and negligible power consumption.[1] Switching is accomplished by the mechanical deflection of a suspended structure and the deflection can be obtained using electrostatic, magnetostatic, piezoelectric, or thermal actuation.[2] To date, the majority of MEMS switches employ electrostatic actuation.[3] However, the actuation mechanism is a nonlinear and usually requires high voltages to operate. These important drawbacks are undesired considering their application in handheld wireless communication systems like mobile phones.[4,5]

In contrast, piezoelectric actuation is a linear, can operate lower voltages. In addition, the mechanism allows the design of larger contacts for high power capability as well as improved reliability due to

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mitigated stiction effects.[4] Lead zirconate titanate (PZT) is a representative piezoelectric material and a number of surface micromachined actuator utilizing PZT films have been reported for its high piezoelectric coefficient.[5] Recently, for high performance piezoelectric RF-MEMS switches, PZT thin film is deposited on the structure layer directly which is used to increase deflection as well as support structure when the PZT is poled in the transverse direction and actuated in the d33 modes.[4,5] It is well known that the magnitude of the d33 coefficient of PZT is about twice the d31 coefficient.[5]

The piezoelectric MEMS switches are largely composed of piezoelectric layer, structure layer and electrode. And it is important that choose a set of structural and sacrificial material for simpler and cheaper process. The common sets are polycrystalline silicon/silicon dioxide, polyimide /aluminum, Silicon nitride/polycrystalline silicon and tungsten/silicon dioxide, etc.[6]

In this paper, we present a set of structural and sacrificial material that is DLC/photoresist for high performance PZT RF-MEMS switches. A photoresist sacrificial layer has many advantages that is easy to coat, easy to dissolve, can be patterned and is compatible with the materials and processes used in conventional IC manufacturing.[7] But the entire process must to be done under 200oC which is curing temperature. DLC film can be prepared at relatively low temperatures by radio frequency plasma enhanced chemical vapor deposition (RF-PECVD) method, which has been widely used for the synthesis of DLC thin film because it uses standard plasma processing technology that allows the simple and relatively inexpensive low-temperature coating of a range of temperature sensitive substrates and can be uniformly coated on the substrate of different shapes and sizes[8] and easily control the DLC properties by controlling the hydrogen contents in the film.[9] Therefore DLC film is suitable for structure layer which process use photoresist as a sacrificial layer.[10] And this fabrication of MEMS becomes much simpler and cheaper with the use of a photoresist as a sacrificial layer. And particular attention is paid to the annealing of PZT film in order to crystallize of PZT film into perovskite maintaining the properties of DLC film.

Ⅱ. Experiment

1. Fabrication

The basic process steps are illustrated in figure 1.

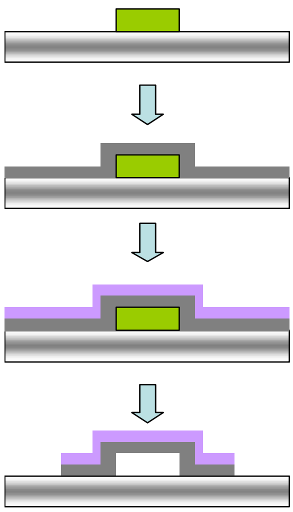

Figure 1. Basic process steps for fabricate structure

First, a photoresist sacrificial layer is spun on a substrate and patterned by using standard lithography procedure and photoresist fabrication techniques. The entire process until the removal of the sacrificial layer is kept below 180oC. Therefore there is no heating process except by plasma.

Next, methane and nitrogen gases are then introduced into the reaction chamber to grow the films at room temperature by RF-PECVD method. (step 2) The substrate is heated only by the plasma during the film growth and the deposition time was kept as 5 min 30 sec for every sample. The deposition condition is shown Table 1.

In step 3, PZT thin film is prepared by rf magnetron sputtering system using $Pb_{1.1}(Z_{r0.52}T_{i0.48})O_3$commercial ceramic target. Table 1 shows the deposition condition of PZT thin film.

Table 1. Deposition condition of DLC thin films

Deposition gas	CH_4: 20 sccm H_2: 80 sccm
Working pressure	1 Torr
RF power	150 W
Electrode to substrate distance	7 cm
Deposition time	5 min 30 sec
Substrate temperature	Room Temperature

Table 2. Sputtering condition of PZT thin films

Target	2 inch 10% access PZT ceramic target
Substrate	Si (100)
Working pressure	5×10^{-3} Torr
Ar : O_2 flow rate	16 : 4
RF power	125 W
Substrate temperature	Room temperature
Film thickness	400 nm
Deposition time	120 min

Finally, each layer is pattered and the structure is released. And then the structure is annealed by rapid thermal annealing (RTA) equipment for 180 seconds in order to crystallize of PZT film into perovskite.

2. Application on Genetic Algorithm

The surface morphology and properties of DLC and PZT thin films are analyzed using an atomic force microscope (AFM), X-ray diffraction (XRD).

Toinvestigate change of the film properties according to annealing temperature and to decide PZT annealing condition which process is needed tocrystallize of PZT film into perovskite. The experiment is done by RTA equipment after DLC deposition step in oxygen ambient as a function of annealing temperature from 300 to 900℃ in steps of 200℃. The hardness and Young's modulus of the film are analyzed using a nano-indenter.

Ⅲ. Result and Discussion

The AFM images of each layer is shown figure 2. DLC thin film is good for under layer in aspect to surface roughness. The value of surface roughness (RMS) of DLC film and PZT film deposited on DLC layer are 0.22 nm and 1.05 nm, respectively.

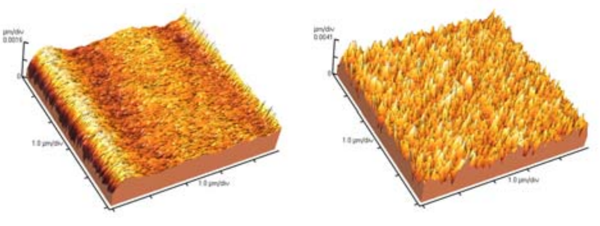

Figure 2. AFM images of films : (a) DLC film and (b) PZT film

Fig. 3 shows the hardness and Young's modulus of as-deposited and annealed DLC films at 300, 500, 700, and 900℃ with a nano-indenter measurement. The hardness abruptly decreases from 20.3 to 12.7 GPa between500 and 700℃. The post annealing treatment results in the increase of graphitic fraction in the film and clustering of sp^2 bonded carbon. DLC structure layer has strong advantages of hardness and Young's modulus in spite of decreasing their values.

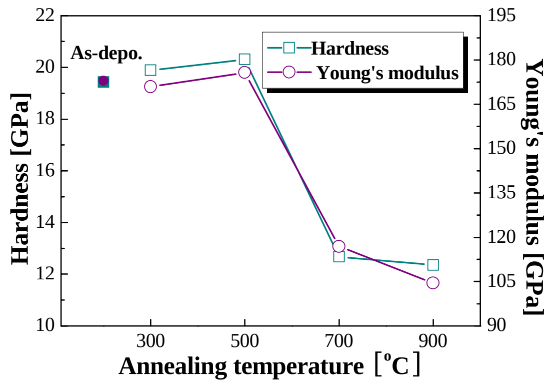

Figure 3. Hardness and Young's modulus of DLC films as a function of annealing temperature

The XRD pattern of the PZT thin film is shown in Figure 4. The perovskite structure of PZT thin films is obtained by RTA treatment for 180 seconds over 600oC. We have reported that the oriented sample by the RTA treatment can improve the electrical property of PZT thin film.

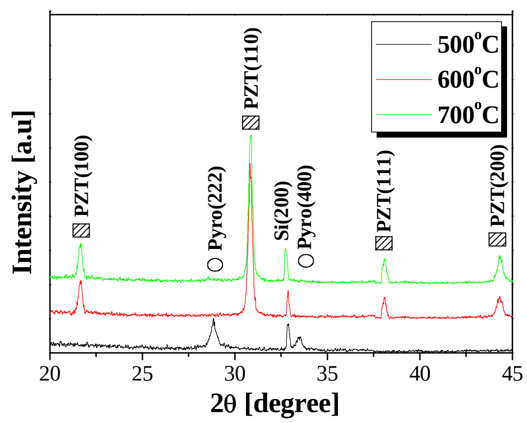

Figure 4. XRD patterns of PZT thin films as a function of annealing temperature

Ⅳ. Conclusion

A new set of structural and sacrificial material that is DLC/photoresist for PZT RF-MEMS switches has been suggested. Photoresist sacrificial layer has many advantages that is easy to coat and dissolve but the process must to be done at low temperature to avoid photoresist curing. DLC film is prepared at room temperature by RF-PECVD method and shows good performance for structure layer in aspect to Young's modulus and hardness. The PZT film which is deposited on DLC layer is well crystallize into perovskite structure. The fabrication of micromechanical systems becomes much simpler and cheaper with use of a photoresist.

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