PECVD SiO$_2$/Si$_3$N$_4$ DOUBLE LAYERS ELECTRETS FOR APPLICATION IN MEMS POWER GENERATOR

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Abstract: This paper reports SiO$_2$/Si$_3$N$_4$ double layers electrets both prepared by PECVD on glass substrates. Their charge stability and isothermal charge decay were studied. Effects of Si$_3$N$_4$ thickness on the performance of double layers electret were investigated. Different methods of treatment were employed to improve charge stability under high humidity conditions. The experimental results show that PECVD prepared SiO$_2$/Si$_3$N$_4$ double layers exhibit high performance under different environmental conditions. At last, an MEMS power generator structure with 10µm PECVD SiO$_2$/Si$_3$N$_4$ double layers as electret was successfully fabricated by a bulk micromachining process.

Key Words: electret, PECVD SiO$_2$/Si$_3$N$_4$ double layers, MEMS power generator

1. INTRODUCTION

Electrets are widely applied in electric-acoustic transducers [1], biomedicine [2], electrostatic power-generators [3] and etc. Because of their stable charge storage, silicon-based inorganic electrets, such as SiO$_2$ and Si$_3$N$_4$, have been well studied for their high charge stability and compatibility to IC and micromachining technologies [4].

Electret MEMS power generators are purely electric, clean, long-lifetime and high-power-output in small scale. However, these MEMS power generators all used organic electrets [5-7], which is difficult to be compatible with micromachining process. SiO$_2$/Si$_3$N$_4$ double layers electrets have been proved better charge stability than single layer of SiO$_2$ or Si$_3$N$_4$. In all papers reached, at least one layer of the SiO$_2$/Si$_3$N$_4$ double layers electrets was deposited by thermal oxidation or APCVD/LPCVD on silicon substrate. The low deposition speed and high residual stress of these techniques lead to difficulties to prepare thick layers (>2µm). However, thick electrets are necessary for low parasitic capacitance and other requirements of micro devices, such as electret power generators demanding electrets as thick as possible. PECVD could be a better choice for its relatively high deposition speed and low residual stress. Furthermore, PECVD’s low deposition temperature makes it feasible to prepare silicon-based inorganic materials on non-silicon substrates with low melting point like glasses, and metal layers as lower electrodes, such as Al, Au, and etc. So PECVD prepared SiO$_2$/Si$_3$N$_4$ double layers electrets can be expected a wide application in miniaturized transducers.

This paper reports SiO$_2$/Si$_3$N$_4$ double layers electrets both prepared by PECVD on glass substrates. Using 10µm PECVD SiO$_2$/Si$_3$N$_4$ double layers as electrets, a bulk micromachining process is also proposed to successfully fabricate an electret MEMS power generator structure.

2. EXPERIMENTAL

Cr (30nm) and Au (100nm) as lower electrode were sputtered on 4-inch Pyrex7740 glass wafers at first. Then, 1µm SiO$_2$ and 100nm Si$_3$N$_4$ was deposited by thermal oxidation or APCVD/LPCVD on silicon substrate. The low deposition speed and high residual stress of these techniques lead to difficulties to prepare thick layers (>2µm). However, thick electrets are necessary for low parasitic capacitance and other requirements of micro devices, such as electret power generators demanding electrets as thick as possible. PECVD could be a better choice for its relatively high deposition speed and low residual stress. Furthermore, PECVD’s low deposition temperature makes it feasible to prepare silicon-based inorganic materials on non-silicon substrates with low melting point like glasses, and metal layers as lower electrodes, such as Al, Au, and etc. So PECVD prepared SiO$_2$/Si$_3$N$_4$ double layers electrets can be expected a wide application in miniaturized transducers.

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3. MEASUREMENTS AND RESULTS
3.1 Charge stability
In this paper, the surface potential was measured by Trek 347 voltmeter. The sample charged at typical conditions was then stored in silica gel desiccators at room temperatures. Its surface potential were observed for more than two months and measured once per week. The result is shown in figure 1. It shows that an initial surface potential of -170V can be achieved and the surface potential just decreases about 10V at room temperatures and low relative humidity for more than two months, indicating a good chargeability of PECVD SiO$_2$/Si$_3$N$_4$ double layers.

Isothermal charge decay at different temperatures was shown in figure 2. There is no obvious decay at a temperature below 200°C, further indicating high charge stability of PECVD SiO$_2$/Si$_3$N$_4$ double layers. Temperatures above 300°C can lead to quick charge decay to almost 0V in 150min. The samples lost about 20% of their surface potential after 10 hours' charge decay at 250°C. Therefore, 250°C is an ideal temperature to observe charge decay and to evaluate charge stability and used to compare charge stability on different conditions in following discussions.

3.2 Effect of Si$_3$N$_4$ thickness
The double layers electrets with 2nm-100nm Si$_3$N$_4$ exhibit much better charge stability than SiO$_2$ single layer (as shown in figure 3). They typically lost less than 20% of their surface potential after 10hrs at 250°C. It can be seen that the charge stability of double layers with 2nm-100nm Si$_3$N$_4$ is quite similar to each other. And just 2nm Si$_3$N$_4$ layer deposited on SiO$_2$ layer could improve the charge stability significantly. However, when the Si$_3$N$_4$ thickness increased to 1um, the charge stability was even worse than single SiO$_2$ layer. Its surface potential gradually decreased to about 0V after 10hrs at 250°C.

3.3 Method to improvement of Charge stability
As for electrets materials, the adhesion of water molecules in the air would increase the surface conductance and thus accelerate the charge decay. The above discussions are all based on the precondition that the samples are stored in silica gel desiccators, a very low humidity environment. In order to observe the performance of electrets in high humid environment, samples were prepared at first and then put in a humidistator with 95%RH at 25°C for 10hrs. Surface potential was measured once an hour.

Common methods like heat treatment, HMDS process and O$_2$ plasma process are usually applied...
to improve the charge stability of inorganic electrets [4]. In this paper, the above methods and their different combinations were applied to improve the charge stability of PECVD prepared SiO$_2$/Si$_3$N$_4$ double layers electrets in high humid environment: (1) heat treatment after corona charge at 250°C for 3hrs; (2) HMDS treatment after corona charge; (3) O$_2$ plasma treatment for 10mins before corona charge; (4) HMDS treatment after 3hrs’ heat treatment at 250°C after corona charge; (5) O$_2$ plasma treatment for 10mins before corona charge and heat treatment at 250°C for 3hrs after corona charge. The results were shown in figure 4.

It can be seen that the samples without any treatment would lose about 60% of the surface potential after 6 hrs at 95%RH. HMDS process, heat treatment at 250°C and O$_2$ plasma treatment would all improve the charge stability in high humidity conditions. However, the improvement of HMDS process and heat treatment cannot last for a long time. Different to the other two methods, the surface potential of O$_2$ plasma treated samples tended to be stable rather than kept decreasing.

Combinations of HMDS and O$_2$ plasma with heat treatment results show that combined treatment can achieve better charge stability under high humidity conditions. Samples coated by HMDS after 3hrs’ heat treatment at 250°C has more than 93% of the initial surface potential after 10hrs at 95%RH, exhibiting very good charge stability under high humidity conditions. Combined O$_2$ plasma treated before corona charge and heat treated after corona charge also improve charge stability under high humidity conditions significantly. The surface potential decreased little at beginning, and tends to keep constant at about 92% of the initial surface potential after 5hrs. It is shown that combined treatment of O$_2$ plasma process before corona charge and heat treatment after corona charge brings about better stability of PECVD prepared SiO$_2$/Si$_3$N$_4$ double layers under high humidity conditions.

4. FABRICATION OF MEMS POWER GENERATOR STRUCTURE

The 3D schematic MEMS power generator structure is shown in figure 5. Its bulk micromachining process mainly composes of etching of thick electrets, bonding and DRIE techniques as shown in figure 6. 14μm trench on silicon wafer was obtained by KOH wet-etch and then silicon wafer was implanted by phosphor ion. 20nm/100nm Cr/Au as lower electrode was sputtered on glass and patterned by liftoff. Then, SiO$_2$/Si$_3$N$_4$/SiC (10μm/100nm/0.5μm) dielectric layers were deposited by PECVD. RIE was
employed to pattern the hard mask SiC layers and Si$_3$N$_4$ layers. 10μm SiO$_2$ were wet-etched by BHF and then SiC was removed. Glass and silicon wafers were anodically bonded together at 350°C and 1000V. Silicon wafer was etched back till 80μm thick silicon left. Movable structure was released by DRIE. Photograph of patterned 10μm/100nm SiO$_2$/Si$_3$N$_4$ double layers on the lower electrode was shown in figure 7. Figure 8 shows the photograph of our MEMS power generator’s structure realized by above process.

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