The Effect of Hafnium Dioxide Nanofilm on the Organic Thin Film Transistor

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Abstract

Hafnium dioxide nano film as gate insulator for organic thin film transistors is prepared by atomic layer deposition. Mostly crystalline of HfO_2 *films can be obtained with oxygen plasma and with water at relatively low temperature of* 150^oC. HfO_2 *was deposited as a uniform rate* $1.2A^o$*/cycle. The morphology and performances of OTFT will be discussed.*

1. Introduction

Organic molecular thin film transistor have been widely studied due to their potential for applications related to large area, low-cost electronics and their compatibility with flexible substrate.[1] The carrier mobilities that are observed for OTFT fabricated from pentacene are comparable with those of amorphous silicon and have attractive interest. Most of work related gate insulators are organic materials and silicon dioxide. Hafnium dioxides is considered as a potential gate insulator due to its relatively high dielectric constant around 30 and large band gap around 5.68eV [2]

Atomic layer deposition (ALD) for semiconductor industry is used for the fabrication of uniform and dense nano films due to the easy control of thickness and improved film quality at relatively low temperature. Plasma enhanced (PE) ALD with shower head reactor and ALD with traveling-wave reactor were used for ZnO film fabrication on silicon wafer by using plasma and water as reactants, respectively.[3] Recently, there was a report on the HfO_2 as a potential substitute for SiO_2 gate insulator, however, they reported the interfacial properties of HfO_2 as a ALD film on the silicon wafer.[4]

In this paper, we prepared and characterized HfO_2 nano film by PEALD to investigate the effect of naon film quality and prove low temperature process for the compatibility of flexible substrates.

2. Experimental

HfO_2 films were deposited on 4” p-type silicon wafer and glass after cleansing by ALD at the temperature 200^oC and 250^oC, respectively. The source delivery system for ALD is using bubbler type delivery system like Fig. 1. As a source of hafnium tetrakis(ethylmethylamino) hafnium (TEMAH) was used. Oxygen plasma and water were used as oxygen precursors for nanofilm fabrication. The reactor pressure was maintained 0.6 Torr with the Ar purging of 100 sccm. During the reaction TEMAH and oxygen plasma were sequentially injected into the reactor chamber to form HfO_2 monolayer on the substrate. ALD cycle consisted of the injection of TEMAH for 0.5s, Ar for 5sec, O_2 gas for 0.5sec, and additional 2sec with rf power of 60W, and final purge for 20sec.

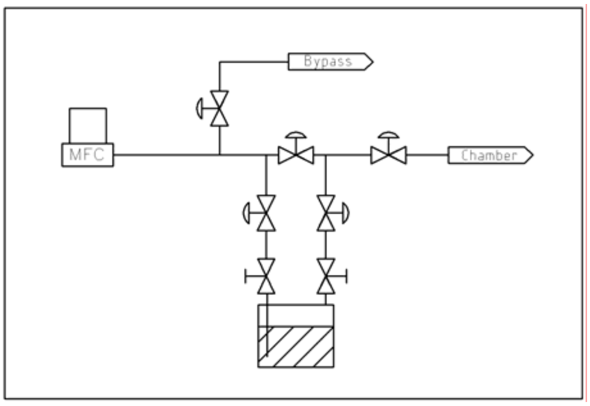


Fig. 1 Schematic diagram of bubbler type source delivery system for ALD

Pentacene as a semiconductor was deposited on the wafer and on the glass substrate under high vacuum thermal evaporator. The thickness of pentacene was about $600A^o$ and that of the gold as source and drain was $700A^o$. The structure of OTFT was bottom contact.

3. Results and Discussion

The growth rate of nanofilm (average film thickness per cycle) was examined as a function of precursor pulse time and reaction cycle. The growth rate was about 1.2 A^o/cycle and it was reasonable higher rate comparing previous ALD methods.[5] They used $HfCl_4$ as a source precursor and water as reactant. The obtained the thickness of $0.95A^o$/cycle at 200 ^oC and $0.64A^o$/cycle at 300 C. We used different source of TEMAH and reactant of oxygen plasma and water, and also different system. Even though in water system in our experiment, similar result of growth rate was obtained.

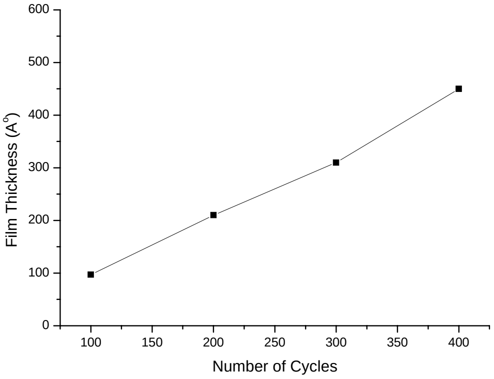


Fig. 2 Total film thickness of HfO_2 with reaction cycles.

We changed the distant of showerhead type reactor in the process module to see the uniformity of the HfO_2 film. The effect of showerhead distant on the thickness is not critical, however, it showed about small differences between the distances. Considering the experimental error the difference between distant is negligible in this system.

The crystallographic orientation of prepared HfO_2 film was examined by an X-ray diffractometer (XRD). Polycrystalline structure of HfO_2 film was obtained.

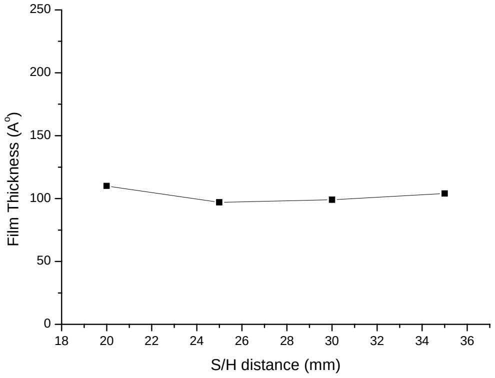


Fig.3 Effect of showerhead distance in the process module on the HfO_2 film thickness

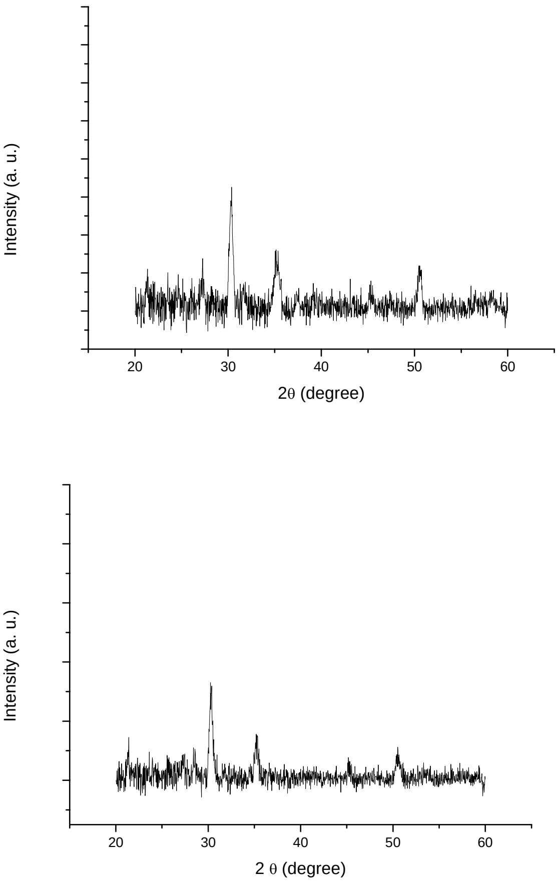
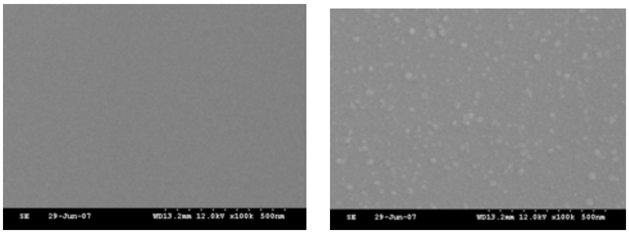


Fig. 4 X-Ray diffraction pattern of hafnium oxide prepared on glass with water (above) and oxygen plasma (below)

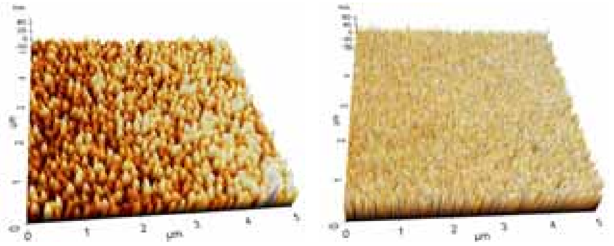
It was reported that the hafnium oxide films prepared by ALD at 200^{o}C was amorphous while the film deposited at 300^{o}C was partially crystalline. And the films deposited at 400^{o}C were mostly crystalline as monoclinic and orthorhombic. [5] In this experiment, crystalline HfO_2 of (111) direction at 31.1^{o} and (002) direction at 35.1^{o} shows preferred orientation with minor peak of (T11) at 27.3^{o}. In this experiment, therefore, mostly crystalline of HfO_2 film can be obtained at relatively low temperature at 200^{o}C comparing previous result.



a) water b) plasma

Fig. 5 SEM image of HfO_2 film prepared with water and plasma, respectively

From the SEM image film crystalline structure of HfO_2 can be seen. In case of plasma, the thickness of film is four times of that of water. Anyhow, the morphology of films needs to be investigated.



a) water b) plasma

Fig. 6 AFM topography of hafnium oxide film

From AFM topography in Fig. 6, the surface roughness of OTFT devices is compared with water and oxide plasma reactants, respectively. Pentacene on hafnium oxide prepared with water looks more uniform than that with plasma. The roughness of pentacene from water is 0.9nm while that from plasma is 2.8nm. The peak to valley of pentacene from water is lower than that from plasma.

The structure of OTFT in this experiment is bottom contact. Two different substrates, silicon wafer and ITO coated glass, were used for fabrication. The thickness of hafnium prepared by ALD is about 500A^{o}. Gold was used for source and drain metal. Pentacene was deposited to 600A^{o} by thermal evaporator with 0.3A/sec rate. No self assembly monolayer (SAM) was used in this experiment. The transfer curve as in Fig 7 show the on/off ratio of this device is not high and subthreshold slope is very steep. In case of glass substrate, transfer curve in Fig 8 shows that the properties of this device is inferior to that of silicon based one. More experimental result will be discussed.

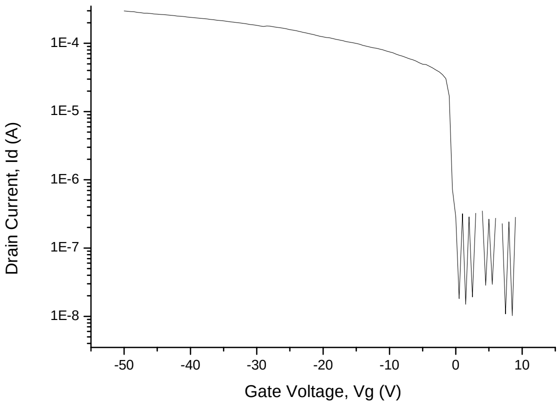


Fig. 7 Transfer curve of OTFT of pentacene on hafnium gate oxide on silicon wafer

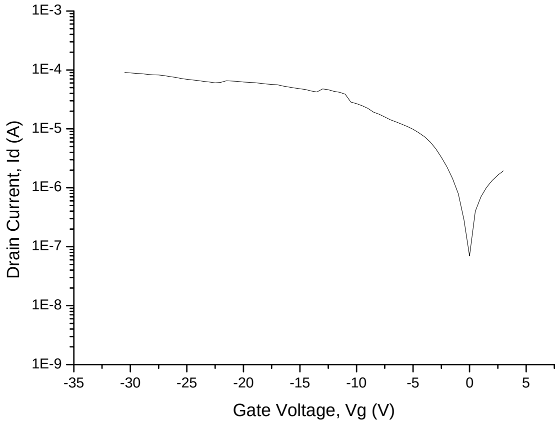


Fig. 8 Transfer curve of OTFT of pentacene on hafnium gate oxide on glass

4. Summary

By ALD method, mostly crystalline of HfO_2 films can be obtained with oxygen plasma and with water at relatively low temperature of 150°C. HfO_2 was deposited as a uniform rate 1.2A°/cycle. OTFT devices prepared with pentacene on wafer and glass can be obtained. The morphology and property are discussed.

Acknowledgements

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