Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp310-311

Study on Microstructure of Gd_2O_3 and Nd_2O_3 Compound Film Formed by RF Magnetron Sputtering

Ziwei Wang, Lei Xiao and Jing Wang

Institute of Microelectronics, Tsinghua University
Tsinghua University, Beijing, 100084, China
Phone: +86-135-2081-6189 E-mail: wangzw13@mails.tsinghua.edu.cn

Abstract

In this paper, we report a Gd_2O_3 and Nd_2O_3 compound film formed by RF magnetron sputtering at 500℃. Crystalline structure and morphological features of the film were studied via XRD, TEM, EDS and AFM measurements. By making rare earth oxide compound lattice coincident to silicon, the film deposited were pseudo-single crystal and had (222) preferred orientation on Si (100) substrate.

1. Introduction

As CMOS devices scale down aggressively, much work have been done on finding the replacement of Si-based oxide in gate dielectrics. The rare earth oxides are promising candidates based on thermodynamic energy consideration and a high conduction band offset [1] [2].

Compared with other high-k dielectrics, rare earth oxides are more likely to be crystallized and show a preferred orientation in specific temperature section [3] [6]. In addition to this, lattice parameters of cube rare earth oxides like Gd_2O_3 (10.81Å), Nd_2O_3 (11.08Å), Er_2O_3 (10.55Å) are nearly twice that of silicon (5.43Å). Therefore they are compatible with silicon, and crystalline rare earth oxides can be epitaxially grown on silicon. In this work, by mingling two rare earth oxides Gd_2O_3 and Nd_2O_3, the rare earth oxides compound is lattice coincident to silicon and pseudo-single crystal combined rare earth oxide film is grown on silicon.

2. General Instructions

Experiment procedure

In order to get the lattice parameter of the mixed crystal to match that of silicon, the component of sputtering target should be calculated prudentially. Vegard's law eq.1 was selected to calculate the percentages of Gd_2O_3 and Nd_2O_3 in sputtering target.

$$A=A1*X1+A2*(1-X1) \qquad (1)$$

A is mixed crystal's lattice parameter. A1 and A2 are constituent crystal (α, β) lattice parameters respectively. X1 is the mole percentages of α in mixed crystal. After calculation, target consists of 81% Gd_2O_3 and 19% Nd_2O_3, which meets the requirements. Ideally the lattice parameter of the film sputtering by target is twice that of silicon, which promotes crystallization of film.

The film was deposited in an integrated multi-chamber ultra high vacuum system using RF magnetron sputtering. The Si (100) substrates were wet chemically cleaned using the RAC method with a final 60s HF (1:10) dip. After that the wafers were immediately loaded into the load-lock and transferred to the UHV growth chamber in order to restrain oxidation of the wafers. The film was deposited at 500°C with deposition pressure of $10*10^{-3}$ torr in Ar ambient and the sputtering power density was $200W/cm^2$.

Results and discussion

A detailed study of the crystalline structure of the film was conducted by x-ray diffraction (XRD) and transmission electron microscope (TEM) measurements.

The XRD measurements for the as-deposited samples are shown in Fig.1. It presents two intense diffraction peaks at $2\theta=68.70°$and $2\theta=28.02°$. The main peak at $2\theta=68.70°$ can be associated with reflections for the (004) plane of the silicon substrate, the other peak at $2\theta=28.02°$ exhibits reflections for the (222) plane of the mixed crystal of Gd_2O_3 and Nd_2O_3 [4] [5] [6]. Gd_2O_3 and Nd_2O_3 are cubic crystals, so lattice parameter of mixed crystal can be calculated which is 11.02Å. The lattice parameter of the mixed crystal is almost twice that of the silicon and the relative error is only 1.5%, which indicates that the rare earth oxides compound matches silicon well.

TEM investigations of the sample are shown in Fig.2. The Fig.2 (a) shows the pseudo-single crystal on Si (100) with additional amorphous interfacial layer of around 4nm. The amorphous interface has been improved to be Gd and Nd silicate [4], and can be transformed to crystal by high temperature thermal annealing. Silicon cap layer was deposited on the film before annealing, which can protect the crystal film. Sample after annealing (1000°C/8hours) in nitrogen ambient is shown in Fig.2 (b). The interfacial layer disappeared and rare earth oxide film was crystallized better during annealing step.

In order to identify the accurate composition of the film, we also conducted energy dispersive spectroscopy (EDS). Fig.3 shows each element's component content along the cross of the films. Content of Gd_2O_3 is about four times as much as that of Nd_2O_3, which is expected.

Fig.4 shows the measurement of atomic force microscope (AFM) which characterizes the flatness of film surface. It shows that surface height standard deviation of the layer is only 0.6nm. The layer deposited is flat enough in the follow-up process and can be a seed layer for other film.

3. Conclusions

By combing Gd_2O_3 and Nd_2O_3, we made rare earth oxide lattice coincident to silicon, and finally got pseudo-single crystal compound film by RF magnetron sputtering in 500°C. XRD and TEM measurements showed that the film was well crystallized and had (222) preferred orientation. We verified chemical component of film by EDS, and AFM showed that the film's surface was smooth enough to deposit other film.

Acknowledgements

This work was supported by Tsinghua Nanofabrication Technology Center. We would like to express sincere thanks to all the engineers for their help and cooperation in the experiment.

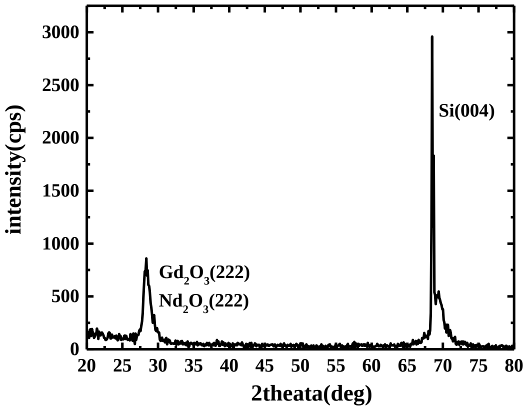

Fig. 1 XRD of rare earth oxide compound film deposited.

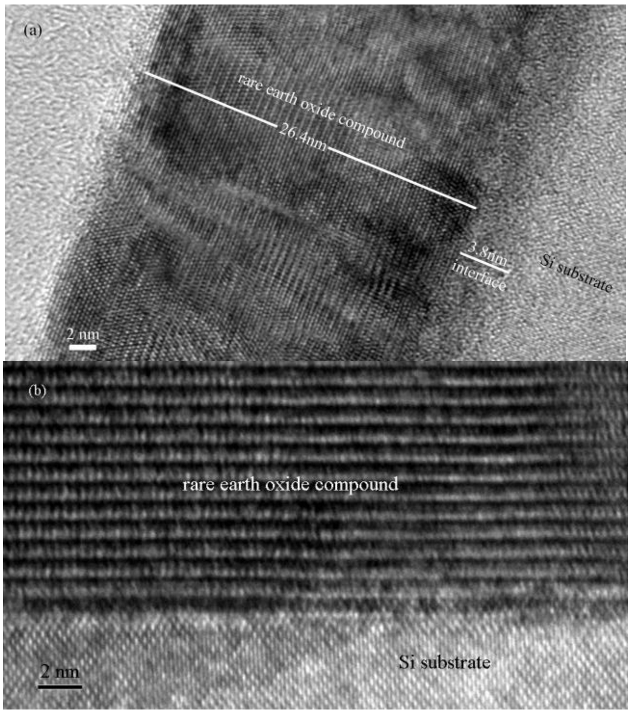

Fig. 2 TEM cross section of rare earth oxide compound film deposited (a) and after annealing (1000°C/8hours) in nitrogen ambient (b).

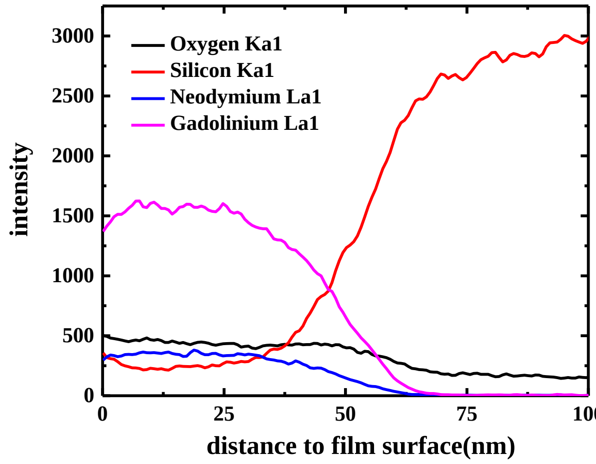

Fig. 3 EDS linescan alone the cross of rare earth oxide compound film deposited which is shown in Fig. 2. Scanned area is from surface to Si substrate.

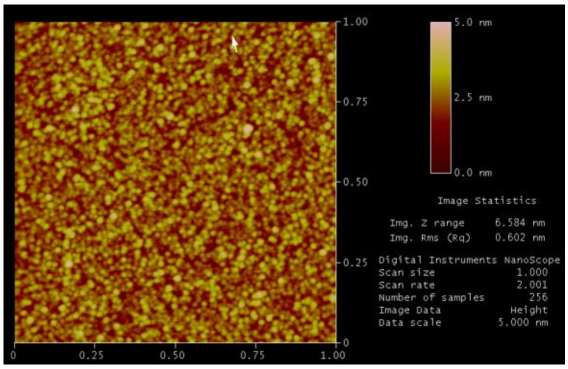

Fig. 4 AFM surface image of rare earth oxide compound film deposited.

References

[1] Kwo J, Hong M, Kortan A R, et al. High ε gate dielectrics Gd2O3 and Y2O3 for silicon[J]. Applied Physics Letters, 2000,77(1):130 - 132.

[2] Kwo J, Hong M, Kortan A, et al. Properties of high kappa gate dielectrics Gd2O3 and Y2O3 for Si[J]. Journal of Applied

[3] Laha A, Osten H J, Fissel A. Impact of Si substrate orientations on electrical properties of crystalline Gd2O3 thin films for high-K application[J]. Applied Physics Letters, 2006, 89(14):143514 - 143514-3.

[4] Pan T M, Lee J D, Yeh W W. Influence of oxygen content on the structural and electrical characteristics of thin neodymium oxide gate dielectrics[J]. Journal of Applied Physics, 2007, 101(2):024110 - 024110-8.

[5] Wang J, Laha A, Fissel A, et al. Structural And Strain Relaxation Study Of Epitaxially Grown Nano-Thick Nd2o3/Si(111) Heterostructure[J]. Nano/micro Engineered & Molecular Systems .nems .ieee International Conference on, 2009:436 - 440.

[6] Kosola A, P01iv01saari J, Putkonen M, et al. Neodymium oxide and neodymium aluminate thin films by atomic layer deposition[J]. Thin Solid Films, 2005, 479:152–159.