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Double SOI Structures and Device Applications with Heteroepitaxial Al_2O_3 and Si

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Growth and properties of a double SOI structure, which consists of epitaxial Al_2O_3 as an insulator layer and epitaxial Si layers, are discussed. LP-CVD(low pressure CVD) for γ-Al_2O_3 (100) growth on Si(100) substrates was combined with AP-CVD for Si growth and a sample exchanging chamber with RHEED and QMS to grow successively and analyzed without exposure to air . This double SOI structure was applied to make a pressure sensor for elevated temperature until 300°C.

1. Introduction

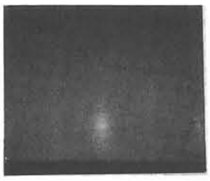
Hetero-epitaxial growth of an insulating layer on Si and the successive growth of single crystalline Si on the insulator(SOI) are of grate interest not only for VLSI but also for new structure devices such as a sensor using micro-machining technology. We proposed an epitaxial Al_2O_3 on Si and $Si/Al_2O_3/Si$ structures.[1,2] The properties of the MOS-FET on the SOI were the same as those of SOS.[3] A pressure sensor for elevated temperature operation (350°C) have been demonstrated using the SOI structure with both a Si direct-bonding technology and a epitaxial Al_2O_3 film.[4]

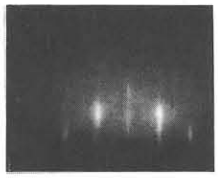
In order to develop this kind of a sensor and a new stacked device, it is very important to investigate the possibility of a multi- layer structure like a double SOI structure of epitaxially grown Si(100) / Al_2O_3 (100) /Si (100) /Al_2O_3 (100) /Si(100) substrate. In this article, we discuss the growth and the characterization of each epitaxial layers of Al_2O_3 and Si grown by a chemical vapor deposition method, and show a device application with the double SOI structure for a high temperature pressure sensor.

2. Double SOI structures

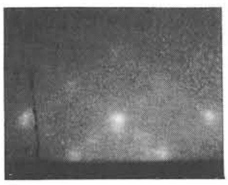
LP-CVD(Low pressure CVD) for Al_2O_3 growth was combined with AP-CVD for Si growth and a sample exchanging chamber with RHEED and QMS to grow successively and analyze without exposure to air. It is well known that H_2O vapor disturbs epitaxial Si on sapphire and results in hazy surface of SOS. In this hetero-epitaxial growth, the same problem should be solved for both growth of Si on γ -Al_2O_3 and vice versa. It is important for preparation of multi-layers to characterize a grown film in-site before the following growth. Therefore, this growth system is better than the previously reported one. $Al(CH_3)_3$(TMA) and N_2O were used as source gasses to Al_2O_3 , and Si_2H_6 to Si. Si(100), 2-inch wafer, was used as a substrate. The growth conditions were the same as the ones reported previously.[3] The epitaxial temperature reduction of 50 and 100°C for Al_2O_3 and Si, respectively was observed and the crystalline quality was also improved compared with the previous results due to the reduction of H_2O partial pressure in the reactor.

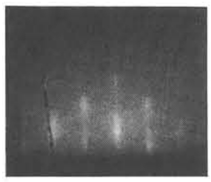
On the basis of the above mentioned result, a double SOI structure was fabricated by growth of Al_2O_3 and Si. The first and the third Al_2O_3(100)films with the thickness of 0.1μm showed mirror-like surfaces and good crystalline quality judged by RHEED as shown in Fig.1. The second and the fourth Si(100) also showed smooth surfaces and streaky RHEED patterns as shown in Fig.1. Figure 2 shows the 3rd Al_2O_3 and the 4th Si epitaxial surfaces, respectively. The double SOI wafer was analyzed by Auger electron spectroscopy(AES) as shown in Fig.3. The multi-layers was confirmed and carbon contaminant in the films was not observed.The defect of these epitaxial Si was studied in comparison with Si on sapphire with KI-I_2 etchant, and was similar to that of a SOS wafer, which was decreased with the Si thickness. In our experiment, all epitaxial Si(100) films on sapphire , Al_2O_3 /Si(100) and Al_2O_3 /Si /Al_2O_3 /Si(100) showed the same results even though the substrates were different. This result means that more multi-layers than this double SOI layer are possible with the same defects. TEM were also used to characterize these layers. The defects of the both Si films such as stacking fault and misfit dislocation were decreased similarly far from the interface between Si and Al_2O_3.





the 1st Al_2O_3 layer   the 2nd Si layer





the 3rd Al_2O_3 layer   the 4th Si layer

Fig. 1 RHEED patterns from each epitaxial layer

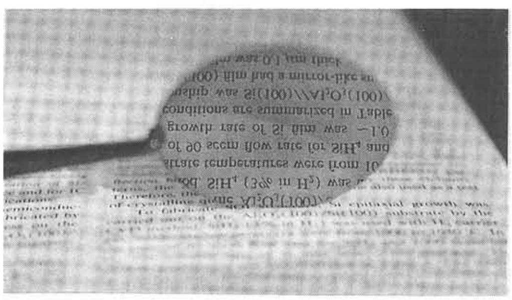


Fig.2(a) Photograph of the 3rd Al_2O_3 epi-layer

Fig.2(b) Photograph of the 4th Si epi-layer

3. Device application

We have already demonstrated the pressure sensors using a single SOI structure of $Si/Al_2O_3/Si$ or $Si/SiO_2/Si$, and double SOI structure of $Si/Al_2O_3/Si/SiO_2/Si$ with a direct-bonding wafer and epitaxial Al_2O_3 film. However, these structures require a V-groove depth control method [8,9] and by thinning the bonded Si film after Si direct bonding [10], respectively. However, it is very difficult to control diaphragm thickness precisely by these methods.

A newly constructed double SOI structure as shown in Fig.4 supplies an ideal structure to multi-structure devices such as a pressure sensor for elevated

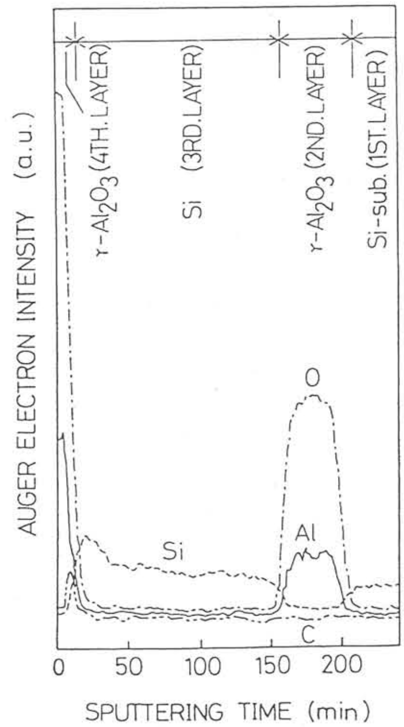


Fig.3 Auger depth profile of Al_2O_3/Si multi-layers

temperatures until 300° with high sensitivity, because piezoresistors can be isolated electrically by the 3rd Al_2O_3 instead of pn junction. Accurate and uniform controlling of thin diaphragm thickness can be done using the 1st Al_2O_3 layer as an etching stop layer due to a stable Al_2O_3 to Si anisotropic etching of KOH solution, and the 2nd epitaxial Si as a thickness and strain adjusting layer of a diaphragm. Pressure sensitivity is inversely proportional to the square of the diaphragm thickness. Therefore, the thickness control of the diaphragm is critical for achieving the desired performance. The etched surface morphology is excellently flat compared with etched Si surface.[11] These nonuniformity in the etched diaphragm cause variation in the pressure sensitivity and offset voltage. [12,13] The diaphragm thickness of 5 μm (4 μm-thick 2nd Si) was used to make a small size diaphragm (360 μm x 1080 μm) with high sensitivity. A high temperature pressure sensor of a single-element four-terminal strain gauge was fabricated on the 4th Si layer(4×10^{18} cm^{-3}).

An operating temperature range of a typically diffused piezoresistive sensor is limited to a temperature of about 150°C due to the leakage current of p-n junctions at high temperatures.[14] However, in the proposed sensor, as the 3rd Al_2O_3 are used as a dielectric isolation of the strain gauge from the 2nd Si layer,the pressure sensor operates at high temperatures up to 300° as shown in Fig.5 with a high sensitivity of 6.5 $mV/VKgfcm^{-2}$ and thermal sensitivity shift less than 2.7%.

4. Conclusions

A double SOI structure with epitaxial Al_2O_3 and Si was grown successfully, and showed the same crystalline quality as that of SOS. The properties of the each epitaxial layer were characterized by RHEED, AES, TEM and defect measurement. The Double SOI structure was a ideal structure of a pressure sensor for a elevated temperature of 300°C, which showed a high sensitivity of 6.5 mV/VKgfcm^{-2} and thermal sensitivity shift less than 2.7%.

Acknowledgement

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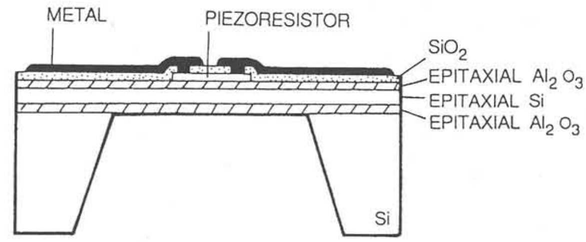

Fig.4(a) Cross section of the pressure sensor with a double SOI structure.

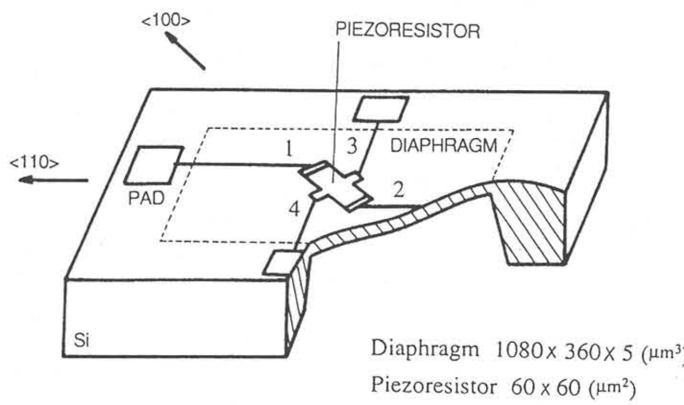

Fig.4(b) The single-element four terminal strain gauge.

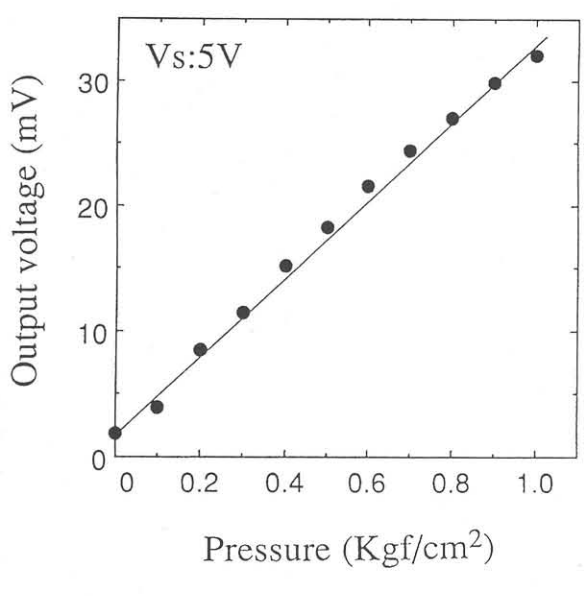

Fig. 5(a) Characteristics of the high temperature pressure sensor

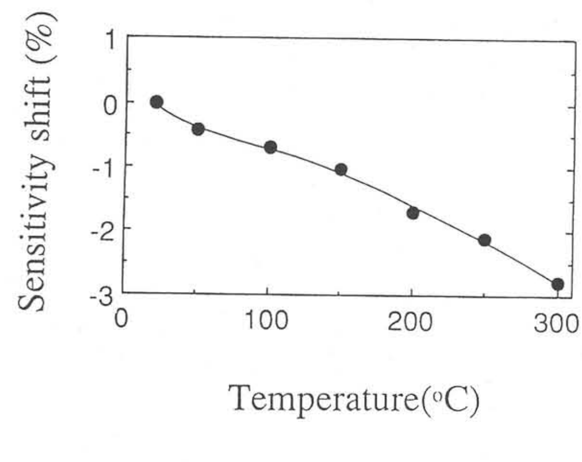

Fig.5(b) Temperature characteristics of the sensitivity