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Fabrication of Ta_2O_5-Si System with Low Density of Interface States and Deep Traps by Plasma Enhanced Liquid Source CVD

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Recently considerable amount of work has been done on Ta_2O_5 high dielectric constant material, specially its growth, structural and electrical properties are well known [1,2]. However, Ta_2O_5 has not been investigated so far, in the areas of interface states and deep traps, to the best of our knowledge and therefore is the aim of the present work.

Tantalum penta oxide was deposited by plasma-enhanced LS-CVD from $Ta(OC_2H_5)_5$ source and $Au/Ta_2O_5/Si$ MOS structures were fabricated. We have estimated the distribution of interface state density (Nss) within the energy level corresponding to the bandgap of Si by using Terman's differentiation method. The results obtained on the Ta_2O_5-p-Si system is shown in fig. 1, where Nss is as low as 2.5 x 10^{11} cm^{-2}. ev^{-1} below the fermi level and 7 x 10^{11} cm^{-2}. eV^{-1} near the midgap. It passes through a peak at about 0.4 eV. The origin of this peak is unknown, but we believe that surface states at the Ta_2O_5-Si system are caused by the reaction between the Ta atoms and Silicon dangling bonds.

In order to investigate deep traps in Ta_2O_5, we have studied variation in the flat band voltage, V_{FB} as a result of the electric field applied to the $Au/Ta_2O_5/Si$ MOS diode. In fig [2-a,b] we show the effect of an applied field on the C-V curve. A number of samples investigated in both n-Si (not shown in the figure) and p-Si materials showed negligible variation of C-V curve along the voltage axis (fig 2-a) and only one sample resulted in variation along voltage axis (fig.2-b). This particular sample belongs to a different batch of Ta_2O_5 growth. The variation in the total charges as shown in fig (3), is related to ionization of the deep traps lying within the band gap of the Ta_2O_5 layer.

With increasing applied electric fields, the deep traps are ionized almost completely. This is because the variation in Qss comes to a saturation with increase in the applied electric field and at E=10MV/cm, the variation is almost negligible. The total variation in the charges is about 2.37 x 10^{-7} coulomb/cm^2 which corresponds to 1.48 x 10^{12} /cm^2, equivalent deep trap density. Here it is assumed that the deep traps at the interface and inside the Ta_2O_5 layer are uniformily distributed such that the defect density calculated at the interface is expected to be the same inside the Ta_2O_5 film. The other sample which did not show any noticable change in the C-V curve after the application of electric field, results in on order of magnitude lower equivalent deep trap density of 2.4 x 10^{11} cm^{-2}.

Deep traps in the Ta_2O_5 can be caused by native defects such as tantalum and oxygen vacancies and foreign impurities such as carbon. The possibility of deep traps caused by carbon impurities is large due to the fact that the Ta_2O_5 is grown from $Ta(OC_2H_5)_5$, which contains carbon. A proper identification of defects in Ta_2O_5 has, yet to be done.

Next, we also investigated the effect of an applied electric field on the interface state density, obtained by the Terman method (fig. 4). Variation in the Nss is found to be negligible in both the samples (A,B). This is because our as-grown C-V characteristics are very well defined, near ideal and are parallel to ideal C-V curve.

In conclusion, these results strongly suggest low interface state density and deep level defects in Ta_2O_5-Si system. Hence Ta_2O_5 films grown by PE-LS-CVD are of much importance as an oxide capacitors in I.C. technology.

1) H. Shinriki and M. Nakata: IEEE Trans. on Electron Devices 38 (1991) 455.
2) P.A. Murawala et al; Jpn. J. Appl. Phys. 32, 368-375 (1993).

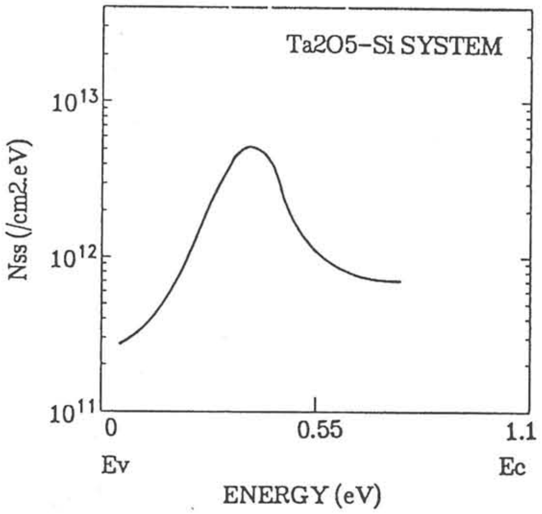
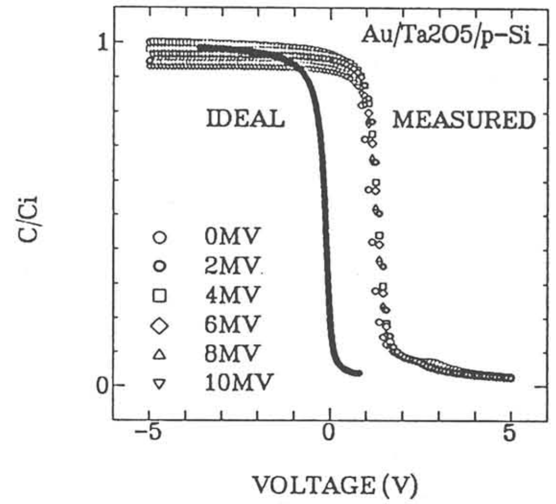
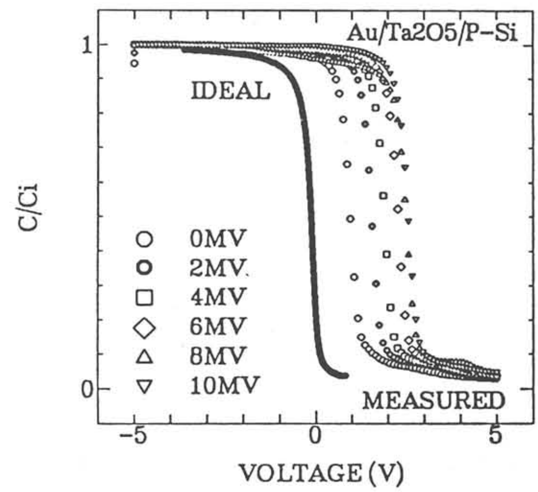


Fig.1 Distribution of interface state density in the Ta_2O_5-Si system, determined by the Terman differentiation procedure.



Sample A



Sample B

Fig.2 Effect of applied electric field on the C-V characteristics of Au/Ta_2O_5/p-Si. Results of two different samples A and B is shown.

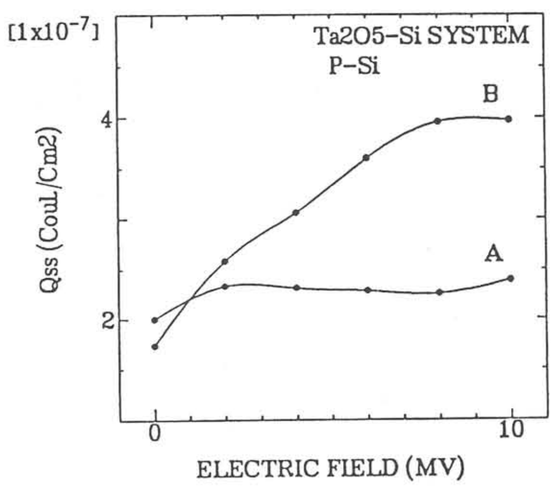


Fig.3 Variation of total charges in Ta_2O_5 film due to applied electric field.

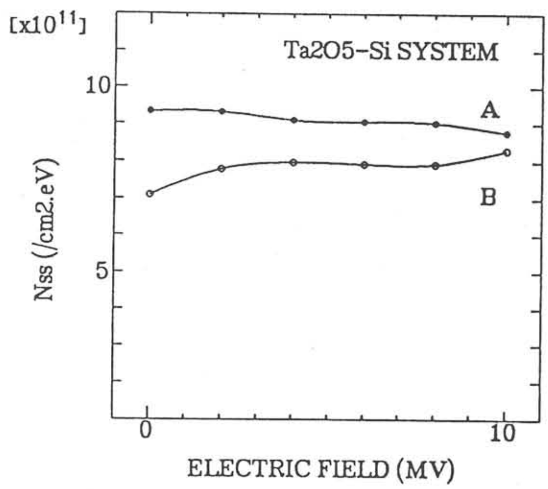


Fig.4 Effect of applied electric fields on the surface state density of Ta_2O_5-Si system.