High Quality Interpoly-Oxynitride Grown by NH_3 Nitridation and N_2O RTA Treatment

Tung Ming Pan, Tan Fu Lei, *Member, IEEE*, Wen Luh Yang, Chun Ming Cheng, and Tien Sheng Chao, *Member, IEEE*

***Abstract*—In this letter, a method to grow high quality interpolysilicon-oxynitride (interpoly-oxynitride) film is proposed. Samples, nitridized by NH_3 with additional N_2O annealing and CVD TEOS deposited on poly-oxynitride (poly-I) with RTA N_2O oxidation, show excellent electrical properties in terms of very high electric breakdown field, low leakage current, high charge to breakdown, and low electron trapping rate. This novel film is a good candidate for an interpoly dielectric of future high density EEPROM and flash memory devices.**

***Index Terms*—N_2O, NH_3, nitridation, oxidation, oxynitride, RTA.**

I. Introduction

THE SCALING down of interpoly dielectrics is critical for next generation nonvolatile memories with a small cell size and low programming voltage. For EEPROM and flash memory devices, the inter-polysilicon oxide demands a high breakdown field and low leakage current to obtain good data retention characteristics. Recently, N_2O grown polyoxide film show excellent electrical properties due to its incorporation of nitrogen at the polyoxide/poly-I interface [1]. However, the nonuniform polyoxide film and rough surface morphology of polysilicon/polyoxide interface in inter-polysilicon oxide cause a lower dielectric breakdown field and higher leakage current. It is previously reported using a CVD TEOS oxide deposited on the phosphorus *in-situ* doped polysilicon and N_2O RTA improves the electrical quality of polyoxide due to smoother interface morphology and incorporation of nitrogen into the polyoxide [2]. In addition, the CMP process achieves a planar surface polysilicon film for polyoxide with a higher electron barrier height and lower electron trapping rate [3]. Therefore, how to reduce the roughness of polysilicon/polyoxide interface and the density of interface defects in the polyoxide become very important topic. However, the Si_3N_4/polysilicon interface is not yet as good as the SiO_2/polysilicon interface and the density of interface defects is also relatively high. An additional N_2O treatment can reduce this interface state and bulk trap densities [4], [5]. In this paper, an interpoly-oxynitride is grown by nitridizing the polysilicon film (poly-I) in NH_3 with an additional N_2O treatment, then a CVD TEOS is deposited on poly-oxynitride and applied with N_2O RTA. Excellent electrical and reliability characteristics are found for this interpoly-oxynitride film.

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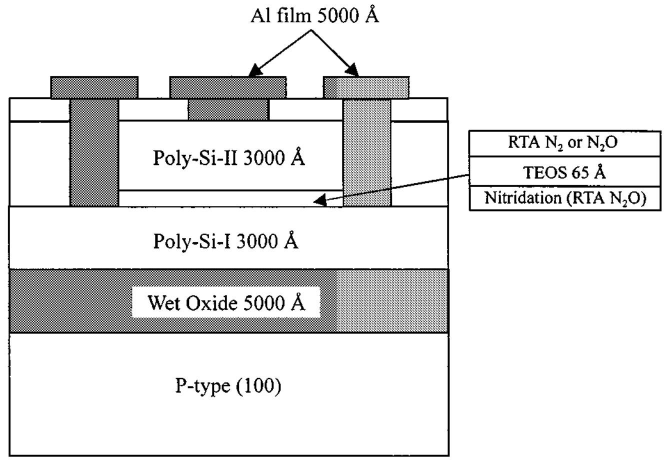

Fig. 1. Cross-sectional view of interpolysilicon-oxynitride film nitridized by NH_3 and TEOS.

II. Experimental

Samples were fabricated on 4-in p-type (100)-oriented silicon wafers. A 5000 Å buffer oxide was thermally grown on the silicon substrate. The poly-Si-I film of 3000 Å thickness was deposited on an oxide in low pressure chemical vapor deposition (LPCVD) system and doped with $POCl_3$ at 900 °C for 30 min, which resulted in a resistivity of 30 to 40 $\Omega/\square$. A Si_3N_4 film was first grown by NH_3 (flow rate is 105 sccm, pressure is 500 mtorr) nitridation of the poly-Si-I layer in LPCVD system at 800 °C for 2 h. All samples were immediately annealed in a N_2O rapid thermal annealing (RTA) treatment at 800 °C for 20 s (NO treatment). Then, an inter-polyoxide layer of 65 Å was deposited on the poly-Si-I by tetra-ethyl-ortho-silicate (TEOS) in LPCVD. These samples were rapid annealed in the rapid thermal reactor (950 °C, 30 s, in N_2 or N_2O ambient). Subsequently, a poly-Si-II of 3000 Å was deposited and doped to obtain a 30 to 40 $\Omega/\square$ resistivity. After the poly-Si-II layer was defined, the samples were thermally grown to 1000 Å by wet oxidation. Contact holes was defined and opened, and Al film was deposited and patterned. Then the wafers were again sintered at 350 °C for 30 min in N_2 ambient, and the capacitor fabrication was finished. A cross-sectional view is shown in Fig. 1. The equivalent oxide thickness (E_{OT}) of an 85 Å interpoly-oxynitride film was obtained from high frequency ca-

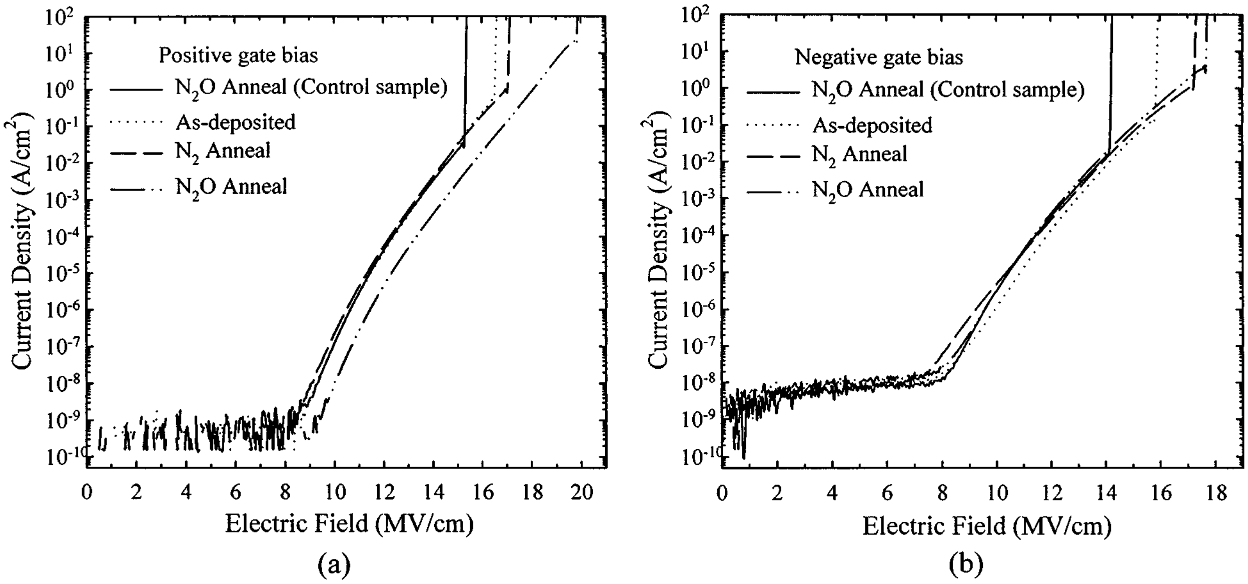

Fig. 2. The J–E characteristics of NH_3-nitridation poly-Si-I film without NO treatment then deposited TEOS with RTA N_2O anneal (control sample), and films with NO treatment then deposited TEOS with RTA N_2 or N_2O anneal, with (a) positive bias and (b) negative bias applied to the top gate.

pacitance–voltage (*C*–*V*). The electrical properties and reliability characteristics of MOS capacitors were measured by using the Hewlett–Packard (HP) 4156B semiconductor parameter analyzer.

III. Results and Discussion

Fig. 2(a) shows positive J–E characteristics of NH_3-nitridation poly-Si-I film for control sample (without NO treatment) or with NO treatment, and then deposited TEOS with RTA N_2 or N_2O annealed at 950 °C for 30 s. It is found that the sample with N_2O oxidation after NH_3-nitridation poly-Si-I film with NO treatment shows the highest electric breakdown field among these samples. This leakage current density for capacitors with NO treatment is lower than that of control sample. This result can be attributed to the smoother surface of polysilicon films (AFM not shown, the roughness of NH_3-nitridation poly-Si-I without NO and with NO treatment are 4.72 nm and 3.98 nm, respectively). In addition, the effective barrier height of the control sample is 2.25 eV and sample with N_2O oxidation after NH_3-nitridation poly-Si-I film with NO treatment has an effective barrier height of 3.08 eV. However, from Fig. 2(b), capacitors with TEOS deposited and N_2O oxidation after NO treatment also exhibit a higher electric breakdown field in the negative J–E curves than the control sample.

Fig. 3(a) and (b) demonstrate Weibull plots of charge to breakdown (Q_{bd}) of capacitors for control sample, TEOS deposited samples under constant current stress of ± 1 mA/cm^2, and deposited TEOS with N_2 annealed or N_2O oxidation under constant current stress of ± 100 mA/cm^2. The deposited TEOS with N_2O oxidation after NO treatment has a larger Weibull distribution than control sample for both polarities. This can be explained by the relative difference of roughness between the bottom and top polyoxide/poly-Si interface. The rough interface enhances the localized electric field resulting in a higher leakage current and a lower Q_{bd}. On the other

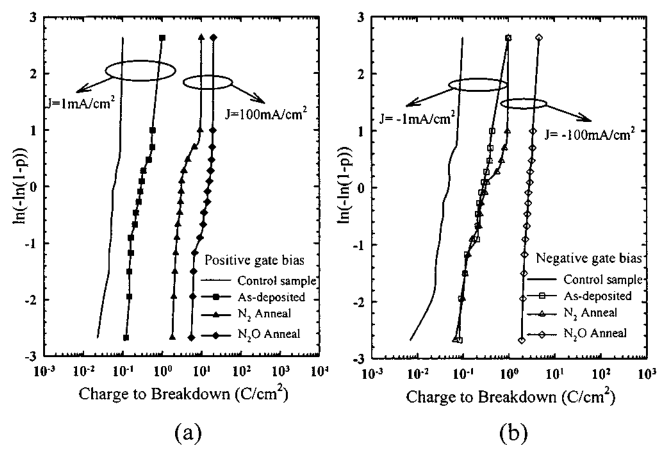

Fig. 3. Weibull plots of charge-to-breakdown (Q_{bd}) of control sample, and samples of NH_3-nitridation poly-Si-I layer with NO treatment and then deposited TEOS with RTA N_2 or N_2O annealed at 950 °C. with (a) positive bias and (b) negative bias applied to the top gate.

hand, nitrogen atoms are piled-up at the polyoxide/poly-Si-I interface and form a nitrogen-rich layer. Therefore, strained Si–O bonds are replaced with un-strained Si–N bonds and bring about a stronger interface. The charge trapping characteristics of deposited TEOS oxide with and without NO treatment was investigated. Fig. 4 depicts the curves of gate voltage shift versus stress time of the interpoly-oxynitride for both stress types of the control sample and deposited TEOS oxide under a constant ± 1 mA/cm^2 current stressing, and deposited TEOS oxide with N_2 or N_2O treatment under a constant ± 100 mA/cm^2 current stressing. All increase in the gate voltage is examined to be due to electron trapping. In spite of a 100 times larger stressing current, the NO treatment with RTA N_2O oxidation of oxynitride shows a much small electron trapping rate than control sample for both polarities. Moreover, the capacitor with NO treatment and RTA N_2O oxidation exhibits a significantly lower electron trapping rate when electrons are

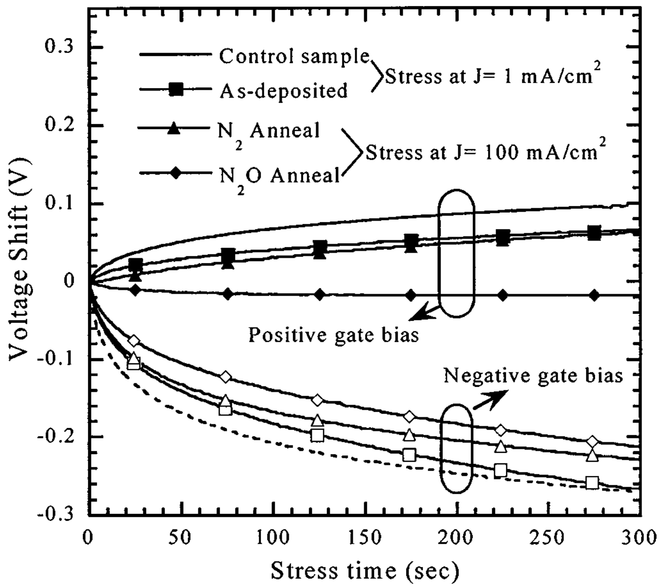

Fig. 4. Curves of gate voltage shift versus stress time of control sample and deposited TEOS under ± 1 mA/cm^2 stressing, and deposited TEOS with RTA N_2 or N_2O annealed at 950 °C under 100 mA/cm^2 stressing on both types.

injected from the poly-Si-I. This means that NO treatment with RTA N_2O oxidation of interpoly-oxynitride has fewer electron traps, which may be ascribed to a smoother interface and more nitrogen incorporation at the polyoxide/poly-Si-I interface.

IV. Conclusion

In this paper, we reported a very promising method to obtain a thin interpoly-oxynitride film by NH_3-nitridation and with a N_2O RTA treatment. This interpoly-oxynitride film exhibits excellent reliability properties in terms of high electric breakdown field and barrier height, low leakage currents and low trapping rate. This novel dielectric film appears to be very promising for future EEPROM and flash memory devices.

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