A-2-1 (Invited) Thermal Nitridation of Silicon in Advanced LSI Processing

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In advanced LSI processing, thinner insulators are required to meet the advantages of fine patterning and smaller device dimensions. Thermal nitride films grown directly on silicon substrates have shown to be the most promising candidates for fabricating thinner insulators because of their high density and freedom from electrical instabilities.

This paper presents procedures for the thermal nitridation of silicon and discusses some of their applications in future LSI processing.

As reported in earlier papers,(1)(2) oxidant impurities in the reactive environment caused nonuniformities in silicon nitride layers. Using the present procedure, chemically cleaned silicon surfaces could be directly converted to uniform silicon nitride layers while being heated in fully purified nitrogen, ammonia or other nitrogen-containing gases at temperatures from 900 to 1300°C. Further, activated nitrogen atoms from, for example, ammonia plasma could be used to effectively decrease nitridation temperatures. In the initial stage, film growth followed the reaction-limited process, while in later stages it seemed to follow the diffusion-limited although it was far from the Deal-Grove oxidation model. Even after several hours of reaction, the thickness of the films remained at about 100Å as shown in Fig. 1. Nitrogen content much more than oxygen in the depth-profile of a film is shown in Fig. 2, where AES was associated with Ar^+ sputtering. No morphologies were observed in the nitrided silicon surfaces by analysis using TEM replica, and no stacking faults or microdefects were found in the silicon substrates.

Because of the strong oxidation-barrier effect of the thermal nitride films and their tight adhesion with silicon substrates, the new selective oxidation is believed to be highly applicable to the fabrication of very fine field patterns. As shown in the cross-section in Fig. 3, bird's beaks were shorter than 0.2μm and there were no dislocations beneath the 70 Å thick nitride masks.

Because of the relatively low energy-barriers, these nitride films were also applied for the realization of low-voltage alterable EAROM cells (NAMIS).(3)

Thermal nitride gate FET's with submicron channel lengths, in which the gate insulators were much thinner than expected from the MOS scaling principle, showed high transconductance, minimized short-channel effects and good stability.(4)

However, one drawback was that both enhancement and depletion devices required fairly high doses of channel ion-implantation, which caused reduction in surface mobilities and degradation in substrate-bias sensitivities. By using a gate electrode material with a relatively high workfunction, such as p^+ poly-Si or metal silicide, this problem could be alleviated. Fig. 4 shows the pattern of a 1/2 to 1/16 frequency divider consisting of J-K flip-flop circuits. The device was fabricated using the thermal nitride film 70 Å thick and p^+ poly-Si gates 1.2μm long. It operated with a toggle frequency of 200 MHz.

In conclusion, the authors believe that the thermal nitridation of silicon could be successfully utilized in advanced LSI processing in which subhundred-angstroms thick thermal nitride films might yield decisive advantages over conventional insulators.

REFERENCES

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(3) T. Ito et al; IEEE ED-26, 6 (1979) 906.

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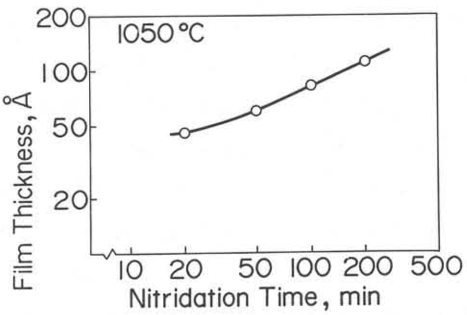

Fig.1. Thermal nitridation of silicon in purified ammonia.

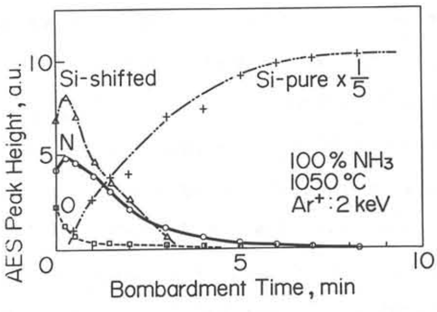

Fig.2. Depth profile by Auger electron spectroscopy.

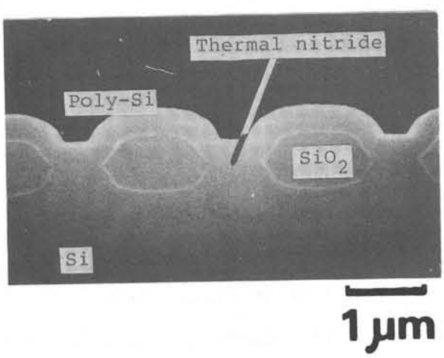

Fig.3. Cross-sectional SEM picture of selectively oxidized silicon.

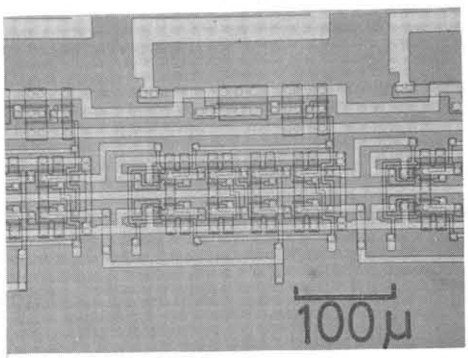

Fig.4. Frequency divider pattern with 70 Å thick thermal nitride films.