

## Structural, optical and electrical properties of SIPOS passivation layers

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*The structure of SIPOS layers depends on the oxygen content and the thermal treatment. As-deposited layers are predominantly amorphous and show instabilities in their electrical properties. We investigated changes in the structure, the conductivity and the optical reflectance dependant on the temperature of a subsequent annealing treatment.*

### 1. INTRODUCTION

SIPOS (semiinsulating polycrystalline silicon) layers [1] have received interest in surface passivation of silicon high voltage power devices [2] as well as in silicon solar cell technology [3]. One of the advantages in comparison to thermal oxide passivation layers is the lower deposition temperature. But inspite of the fact that there exist different opinions about structure and conduction mechanism of the layers [4-6] in practical applications a high temperature annealing treatment is needed to get structural and electrical stability. The effect of different annealing treatments on the properties of SIPOS layers is investigated.

### 2. PREPARATION

The SIPOS layers were prepared by LP-CVD at 650°C from the SiH<sub>4</sub>/N<sub>2</sub>O system with thicknesses of 50 to 500 nm on silicon and thermally oxidized silicon substrates. The gas flow ratio  $\gamma = [\text{N}_2\text{O}]/[\text{SiH}_4]$  was varied from 0.12 to 0.25 producing layers with oxygen contents of  $\alpha = 7...30$  at% as determined by RBS and AES measurements. Subsequently conventional annealing treatments in forming gas (FG: 450°C, 15 min) and dry nitrogen (N<sub>2</sub>: 450, 800, 850 and 900°C, 15 min) and alternatively rapid thermal annealing treatments (RTA: 900, 1000, 1100 and 1200°C, 30s) were carried out. For electrical measurements the SIPOS layers were structured in circular or rectangular islands and aluminium contacts were evaporated.

### 3. TEM INVESTIGATIONS

Using a 100kV transmission electron microscope selected area diffraction (SAD; 0.05  $\mu\text{m}^2$ ) and dark-field image observations (Si  $\langle 111 \rangle$  reflection) were performed on chemically thinned samples. The results shown in fig. 1 indicate a predominantly amorphous structure for the as-deposited layers with a very low density of Si microcrystallites (1 to 2 nm size for layers with about 20 at% O), whereas the crystalline portion and the mean value of the crystallite

size increase with increasing annealing temperature. For lower oxygen contents the crystallization is shifted to lower annealing temperatures. Grain size values shown in tab. 1 are a good extension of the work by Widmer et al. [7] with respect to annealing conditions and oxygen content. The progressive development of Si crystallites with increasing temperature and decreasing oxygen content can be understood as progressive separation of the metastable random bonding  $\text{SiO}_x$  network into the two phases Si and  $\text{SiO}_2$  whereby a formation of thin  $\text{SiO}_2$  shells surrounding the grains is to be assumed as a self-limiting barrier at a given temperature.

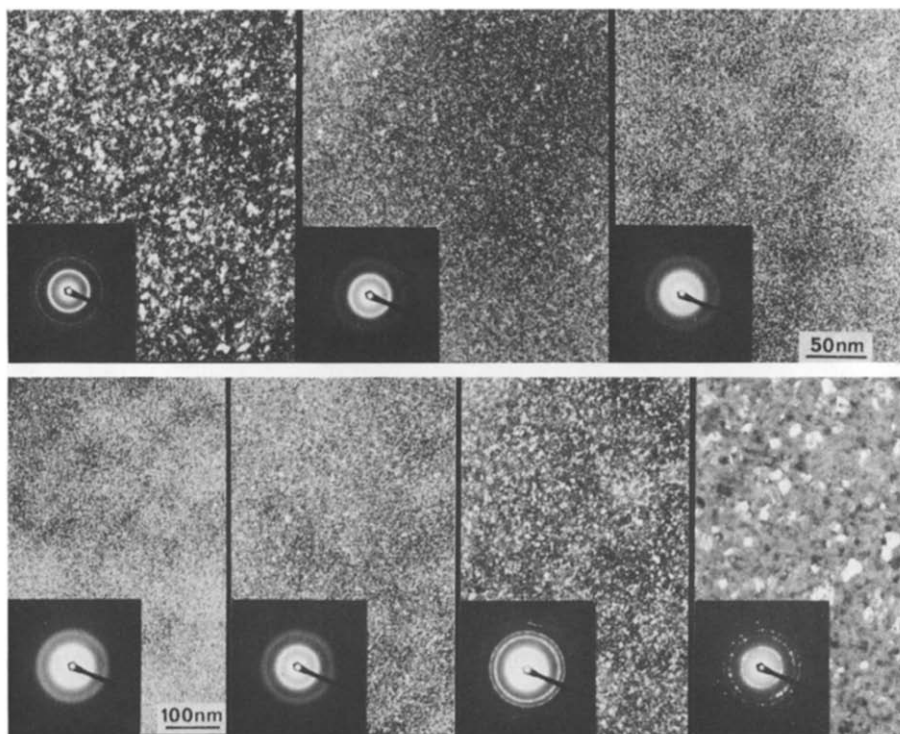


Figure 1. EM dark-field images and SAD patterns of SIPOS samples.

Upper row: 10, 20 and 30 at% O; all annealed at 800°C (conv.).

Lower row: all 20 at% O; as deposited, annealed at 800°C, 900°C (conv.), 1200°C (RTA).

Table 1

Grain size values in dependence on annealing temperature

| $\alpha$ | as deposited | conv. 800°C  | conv. 900°C  | RTA 1200°C    |
|----------|--------------|--------------|--------------|---------------|
| 10 at%   |              | 5 (1..10) nm |              |               |
| 20 at%   | amorphous    | 2 (1..6) nm  | 5 (1..12) nm | 20 (8..50) nm |
| 30 at%   |              | amorphous    |              |               |

#### 4. OPTICAL MEASUREMENTS

The results of the TEM observations are supported by spectral reflectance measurements which give the position of the direct optical transition energies (fig. 2). The critical points of the silicon bandstructure cause the typical features of the curve for single crystalline

silicon shown for comparison. These structures were not found for amorphous silicon due to the loss of long-range order. For the intermediate cases of annealed SIPOS layers the spectra reflect the different degree of crystallinity (different amounts and sizes of Si micro-crystallites) dependant on oxygen content and annealing temperature. One can see that the higher energy peaks are more sensitive to the structural disorder and the size of the micro-crystallites than the low energy gaps. The strongly broadened reflectance maxima (the mean gap) for as-deposited SIPOS and for amorphous silicon are quite comparable.

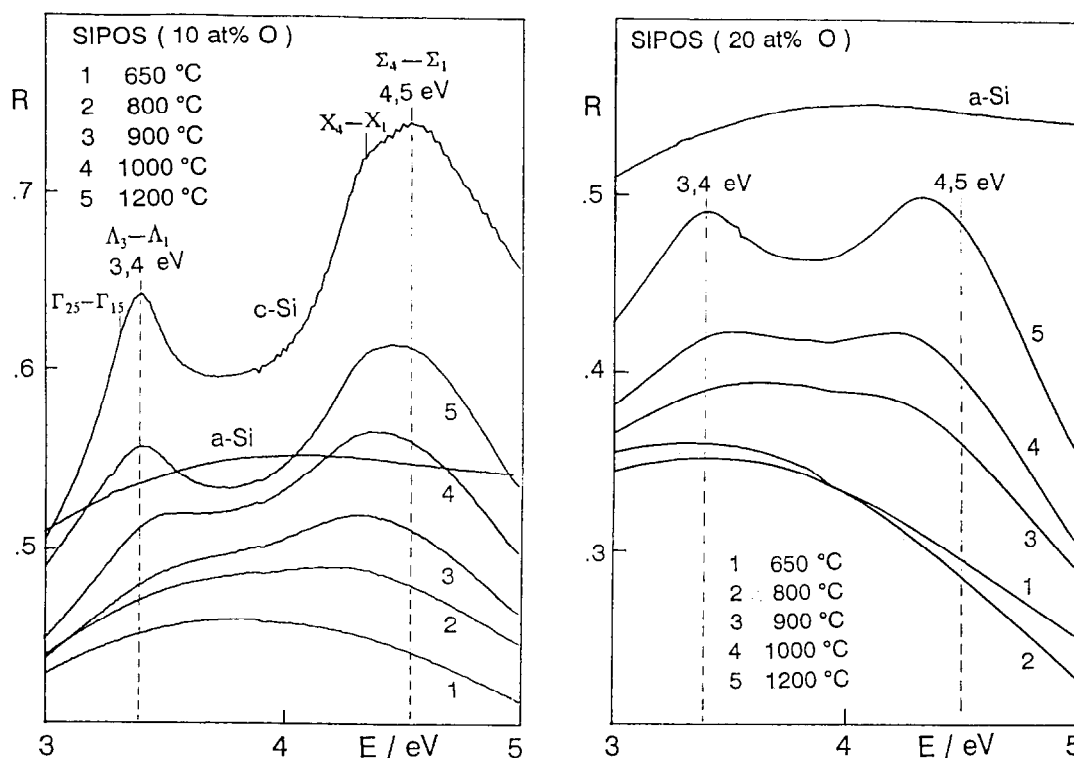


Figure 2. Spectral reflectance  $R(E)$  for SIPOS samples with 10 and 20 at% oxygen, as deposited (1), conv. annealed at 800°C (2) and 900°C (3), RT-annealed at 1000°C (4) and 1200°C (5) and for crystalline (c-Si) and amorphous silicon (a-Si).

## 5. ELECTRICAL MEASUREMENTS

Lateral current-voltage measurements using concentric circular contacts with distances of 10...100  $\mu\text{m}$  show ohmic behaviour for field strengths up to  $\sim 2 \cdot 10^3$  V/cm. The contact resistance was proved to be negligible in comparison to the resistance of the SIPOS layers. The temperature dependent resistivity of as-deposited and low temperature annealed layers shows systematic deviations from exponential law increasing with the oxygen content of SIPOS (fig. 3) and with storage time in air. The deviations can be reversibly decreased by thermal treatments at temperatures of at least 200°C and vanish for layers annealed at higher temperatures ( $T \geq 800^\circ\text{C}$ ). This behaviour, not observed on structures covered by LP-CVD- $\text{SiO}_2$  or  $-\text{Si}_3\text{N}_4$  layers, is regarded to be typical for unprotected SIPOS layers. The time and temperature dependence of resistivity suggests an incorporation of humidity into the layers from the open surface, being in tendency opposite to the effect of built-in hydrogen which

increases the resistivity [8] due to the saturation of dangling bonds.

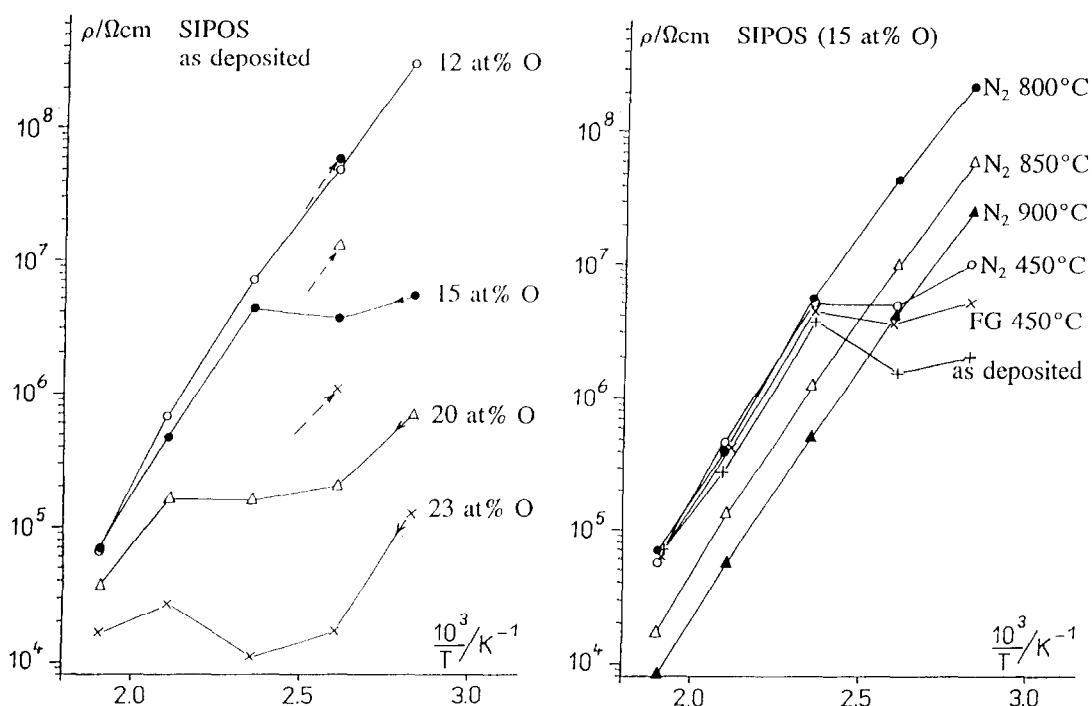


Figure 3. Temperature dependent resistivity of SIPOS layers with different oxygen content and annealing conditions from measurements 3½ month after preparation; arrow-marked points indicate changed resistivity after thermal treatment at 250°C.

## 6. CONCLUSIONS

The structural, chemical and electrical stability of SIPOS layers depends strongly on the degree of crystallinity determined by the oxygen content and the annealing temperature. For middle values of the oxygen content ( $\sim 20\text{at}\%$ ) the transition region between dominating amorphous respectively crystalline phase lies in the range of  $T=800\ldots 900^\circ\text{C}$ .

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