Si-Epitaxy with mixtures of trichlorosilane and silicon tetrachloride precursors at different temperatures

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Epitaxially grown silicon wafers are an alternative for wafers sawn from silicon with a reduced production costs and a lower CO_2 footprint. Currently the quality of these wafers is mostly limited by crystal defects like stacking faults and dislocations [1,2]. Possibilities to reduce the defect density might be an increased ratio of chlorine atoms or an increased temperature during epitaxial growth. Chlorine facilitates local etching of silicon atoms while not perfectly bound atoms are etched more easily. Whereas an increased temperature leads to increased surface mobility of adsorbed silicon atoms and with this to a higher probability for an ideal incorporation into the crystal. Therefore, we investigated epitaxial growth processes with mixtures of trichlorosilane (TCS) and silicon tetrachloride (STC) at different temperatures. We used most ideal chemical mechanically polished 6 inch Cz substrates and measured deposition rate, phosphorus doping incorporation and the crystal-structural quality of the grown layers.

It is known that the deposition rate is reduced by increasing the chlorine content of pure precursors like only STC or only TCS [3]. For mixtures of STC and TCS the deposition rate is, as expected, increasing with increasing TCS amount of the precursor mixture keeping the Cl/H ratio constant. An increase of the deposition temperature by 30 K leads to a slight increase in deposition rate as expected in the diffusion limited growth regime. The homogeneity of the thickness over the used 6 inch wafers is not measurably influenced by gas mixture or temperature.

The phosphorus doping incorporation depends mainly on the phosphine (PH_3) content in the gas mixture and on the deposition rate. Measured phosphorus concentration data show an almost linear dependency on both PH_3 content and deposition rate (leaving the other one constant) in the used parameter range (2.5×10^{15} to 2.5×10^{16} cm^{-3}). With this linear approximation a simple model is established to predict the phosphorus doping concentration dependent on deposition rate and PH_3 flow.

The crystal-structural quality is determined by measuring etch pit density (EPD) and stacking fault density (SFD). The EPD lies for all samples below the detection limit of our current measurement procedure. The highest measured value is 11 EP/cm^{-2} but is over-estimated due to simultaneous measurement of dust particles and etch artefacts with same dimensions. For the SFD no correlation with the gas mixture could be seen. However, a clear trend of decreasing SFD with increasing temperature down to < 2 cm^{-2} is observed. As besides the pure crystal-structural quality the electrical quality is most relevant for producing solar cells with high efficiencies, minority charge carrier lifetimes of epitaxially grown layers deposited at the two different temperatures with specific and relevant doping levels will be measured. The required samples are currently fabricated.

References

[1] S. Janz et al., in 33rd European Photovoltaic Solar Energy Conference. Proceedings (2017), p. 343.
[2] M. M. Kivambe et al., J. Cryst. Growth 483, 57 (2018).
[3] F.C. Eversteyn, Philips Res. Repts 29, 45-66, 1974