IR to UV ellipsometric characterization of silicon nitride thin films on textured Si wafers

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Our message

The film thickness and optical constants can be determined for all the presented textures as well as a virtual void fraction.

New method for measuring thickness in structured c-Si substrates.

The effective dielectric function of Si_xN_y decreases depending on the texture. This can be described by an effective medium approximation consisting of a fully dense Si_xN_y film and void optical constants.

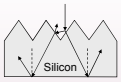
IR data of the chemical bond mode amplitude and resonance energy distribution suggests a change in the chemical composition of the films in dependence on the texture.

Introduction

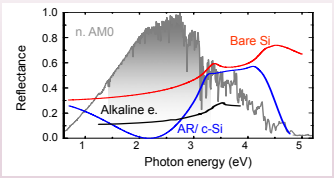
Minimize optical losses in solar cells

Trapping of light techniques:

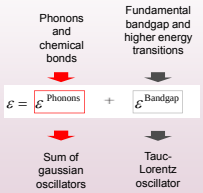
✓ **Surface texturization** [1] ✓ **Anti-reflecting films**



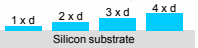
$$d_{AR} = \lambda / 4n(\lambda)$$



Silicon nitride Model Dielectric Function



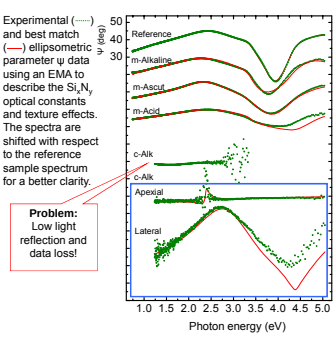
Samples: PECVD grown Si_xN_y films on textured Si



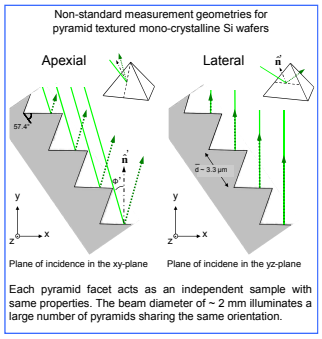
Name	Wafer type	Wafer treatment	Substrate morphology
Reference	crystalline-Si	Polished (no texture)	15 cm
c-Alk	crystalline-Si	Alkaline etched	20 µm
m-Alk	Multi-crystalline Si	Alkaline etched	50 µm
m-Acid		Acid etched	50 µm
m-Ascut		As-cut	20 µm

Results and Discussions

UV-VIS: New measurement method and texture effects



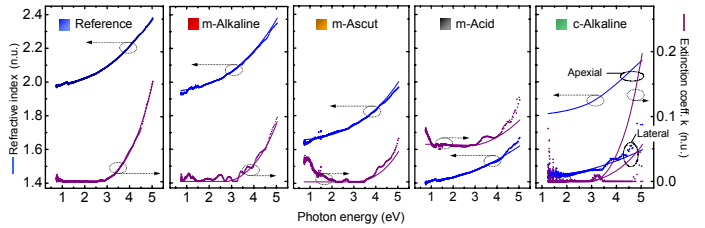
Solution



Each pyramid facet acts as an independent sample with same properties. The beam diameter of ~ 2 mm illuminates a large number of pyramids sharing the same orientation.

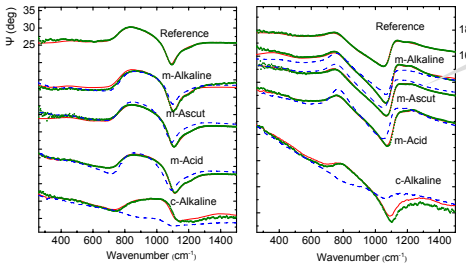
Effective medium approximation (EMA) void-parmeters $\varepsilon = f_{air}\varepsilon_{air} + f_{Ref.}\varepsilon_{Ref.}$

	Reference	m-Alkaline	m-Ascut	m-Acid	c-Alkaline
f_{air}	0	1.4	30.7	50	52.5



Refractive index (—) and extinction coefficient data (—) of the point-by-point extracted (dotted) and best match calculation (solid lines) for the investigated samples.

IR: Chemical bond modes and texture effects

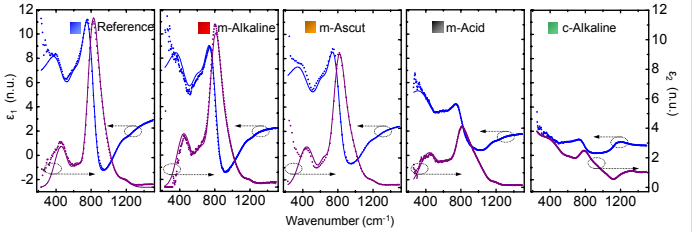


The effective medium approximation (----) is not applicable for the IR data.

While in the NIR-UV spectral range the EMA provided good description of the experimental sata. The EMA provides a poor description for the IR spectral range. This apparent contradiction appears because the IR spectral range is also sensitive to phonon and chemical bond modes, while in the NIR-UV spectral range no modes exist and the dispersion mostly depends on the higher energy electronic transitions.

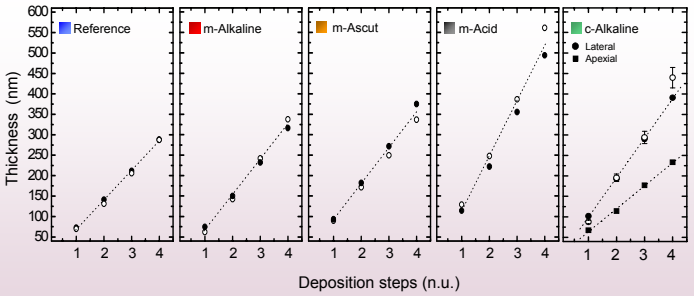
Ellipsometric parameter ψ and Δ in dependence of the wavenumber. The effective medium approximation (----) provides a poor description of the IR experimental data (.....), while the parametric model (—) gives the best match between experiment and model. Measured in the standard geometry at Φ = 55°.

The DF obtained from the UV-VIS and IR analysis present both a decrease of the real and imaginary parts. This effect is addressed to the texture of the substrate. This can be approximated by an EMA combination. The variations in the shape of the spectrum suggest changes in the chemical composition of the films from sample to sample.



Real (—) and imaginary (—) parts of the point-by-point extracted (dotted) and best-match calculation (solid lines) dielectric function of the Si_xN_y films for the different substrate types.

Thickness results



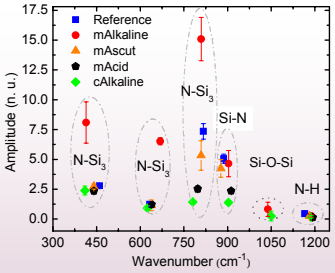
Thickness parameter values plotted versus deposition steps for the different textured wafers obtained from the UV-VIS (●, ■) and IR (○) ellipsometry data analysis.

Chemical modes

Gaussian oscillator model

$$\varepsilon_2' = Ae^{-\left(\frac{E-E_n}{B}\right)^2} + Ae^{-\left(\frac{E+E_n}{B}\right)^2}$$

Changes in the chemical bond modes amplitude and resonance energy parameter values suggest changes in the film chemistry from substrate to substrate. Mode assignation after references [2-4].



Oscillator amplitude versus resonance energy model parameters for the investigated samples.

References

[1] J. D. Hylton et al., J. Electrochem. Soc., 151, G408 (2004).
[2] Z. Yin, *et al.*, Phys. Rev. B **42**, 3666 (1990).
[3] M. Klanjšek Gunde *et al.*, Phys. Status Solidi A **183** (2), 439 (2001).
[4] J. J. Mei, *et al.*, J. Appl. Phys. **100**, 073516 (2006).

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