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Characterisation of thin a-Si on c-Si using Multiple Sample Analysis

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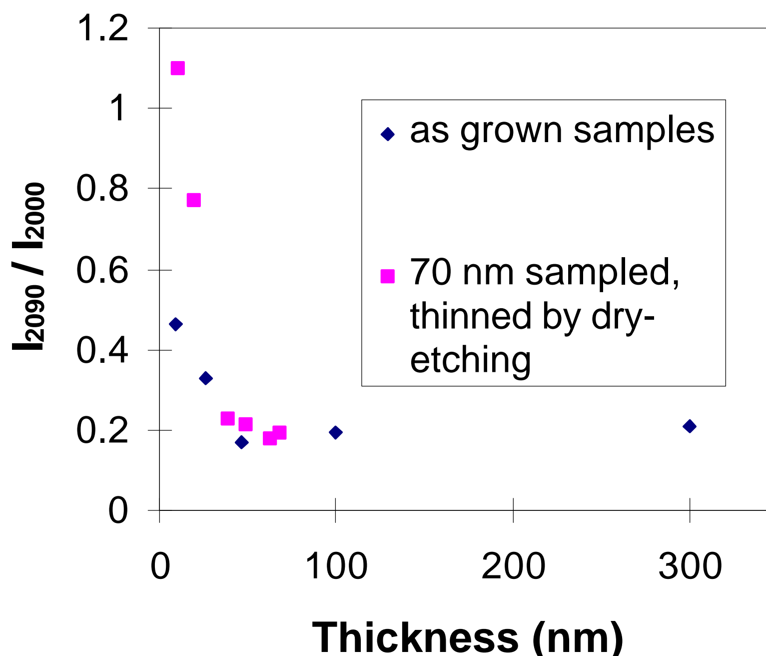
Abstract:

Very thin amorphous silicon films on crystalline silicon wafers have been non-destructively investigated by means of Spectroscopic Ellipsometry. The hydrogen bonding configurations and the sublayer structure of the films have been determined as a function of thickness.

Introduction:

The thickness dependent structure of thin films is a general problem of thin film growth, that has received special attention in the field of the amorphous silicon (a-Si) technology. MIR (Multiple Internal Reflection) measurements on thin a-Si films show a raising SiH_2/SiH concentration ratio (expressed by the ration I_{2090}/I_{2000} of the stretching vibration bands of SiH_2 and SiH) with lower film thickness. The same trend should be measurable using spectroscopic ellipsometry. Increasing SiH_2 concentration for thinner films should reduce the optical density.



Sample preparation:

Five of the samples with different a-Si thicknesses on c-Si grown by Plasma-Enhanced Chemical Vapor Deposition used for MIR spectroscopy have been used for spectroscopic ellipsometric measurements. For better optical contrast additional five samples with equivalent thicknesses have been deposited on silicon wafers coated with about 270 nm of silicon nitride.

Ellipsometry measurements:

The measurements were carried out using a variable angle, rotating-analyzer spectroscopic ellipsometer VASE from Woollam Co, operated in the wavelength range 300 - 1000 nm. The angles of incidence were 71, 74, 77, and 80 degrees. Because of the optical constants and the thickness of such thin a-Si films - in combination with the low optical contrast between substrate c-Si and film a-Si - are strongly correlated we used a special ‘Multiple Sample Analysis’ procedure. In this analysis, several films of the same material but different thickness are measured. During the fitting, the VASE data of all samples are calculated simultaneously, with the optical constants of a-Si of all the samples are set identical and therefore varied simultaneously. This is done by defining an effective optical medium within the Bruggeman approximation, consisting of a-Si and internal void. Because of the optical constants are a function of the thickness, this technique allows to determine the reduction of the optical density for thinner a-Si films correlated to the void concentration.

Typically, if the optical constants for all samples are exactly the same only two to five samples are sufficient to get enough decorrelation of the parameters. In this case we are interested in the optical density as a function of thickness, so ten samples have been combined. It is very important that the film thicknesses are significantly different for different samples otherwise we would not get additional information out of the additional samples. Here we used a-Si films with nominal thicknesses 5, 7.5, 10, 20, and 50 nm. We assumed the thick a-Si film was optically 100% dense, while for the thinner films the reduction in the optical density was modeled by adding a certain percentage of void to the film.

Fit parameters for this multiple sample analysis had been: thickness for each a-Si, SiN and surface SiO_2 as well as void concentration for the four thinner a-Si films.

Sample 1		
2	(sio2) Coupled to #1	2.3467 nm
1	(asi_enea) Coupled to #3	46.186 nm
0	(si_unl) Coupled to #0	1 mm

Sample 6		
4	sio2	2.6912 nm
3	asi_enea	48.277 nm
2	sixnx	274.45 nm
1	sio2	2.3 nm
0	si_unl	1 mm

Sample 2		
2	(sio2) Coupled to #1	1.6082 nm
1	ema (asi_enea)/2.77% void	18.637 nm
0	(si_unl) Coupled to #0	1 mm

Sample 7		
4	(sio2) Coupled to #4	2.1393 nm
3	ema (asi_enea)/2.77% void	19.456 nm
2	(sixnx) Coupled to #2	277.28 nm
1	(sio2) Coupled to #1	2.3 nm
0	(si_unl) Coupled to #0	1 mm

Sample 3		
2	(sio2) Coupled to #1	0.89822 nm
1	ema (asi_enea)/6.81% void	9.7058 nm
0	(si_unl) Coupled to #0	1 mm

Sample 8		
4	(sio2) Coupled to #4	2.3056 nm
3	ema (asi_enea)/6.81% void	9.8595 nm
2	(sixnx) Coupled to #2	271.22 nm
1	(sio2) Coupled to #1	2.3 nm
0	(si_unl) Coupled to #0	1 mm

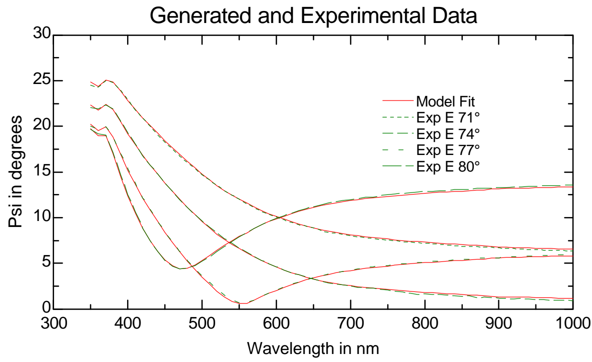
Sample 4		
2	(sio2) Coupled to #1	0.11696 nm
1	ema (asi_enea)/11.5% void	7.2478 nm
0	(si_unl) Coupled to #0	1 mm

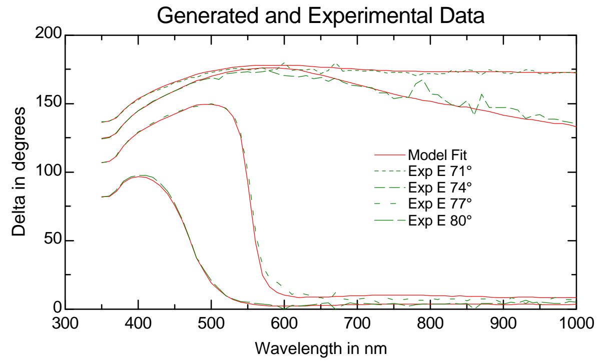
Sample 9		
4	(sio2) Coupled to #4	1.7585 nm
3	ema (asi_enea)/11.5% void	7.8605 nm
2	(sixnx) Coupled to #2	272.19 nm
1	(sio2) Coupled to #1	2.3 nm
0	(si_unl) Coupled to #0	1 mm

Sample 5		
2	(sio2) Coupled to #1	0 nm
1	ema (asi_enea)/17% void	5.4198 nm
0	(si_unl) Coupled to #0	1 mm

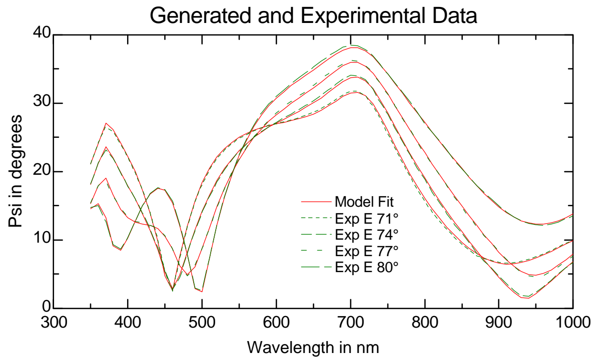
Sample 10		
4	(sio2) Coupled to #4	2.205 nm
3	ema (asi_enea)/17% void	5.6112 nm
2	(sixnx) Coupled to #2	273.28 nm
1	(sio2) Coupled to #1	2.3 nm
0	(si_unl) Coupled to #0	1 mm

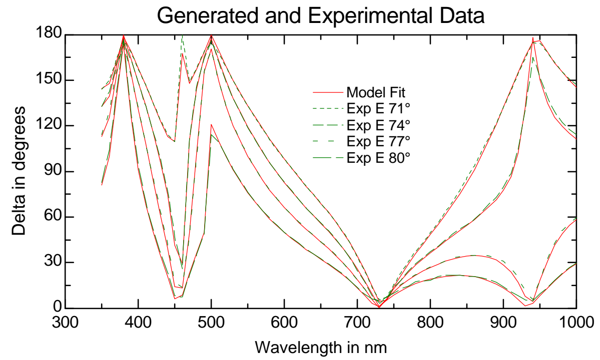
Sample 3

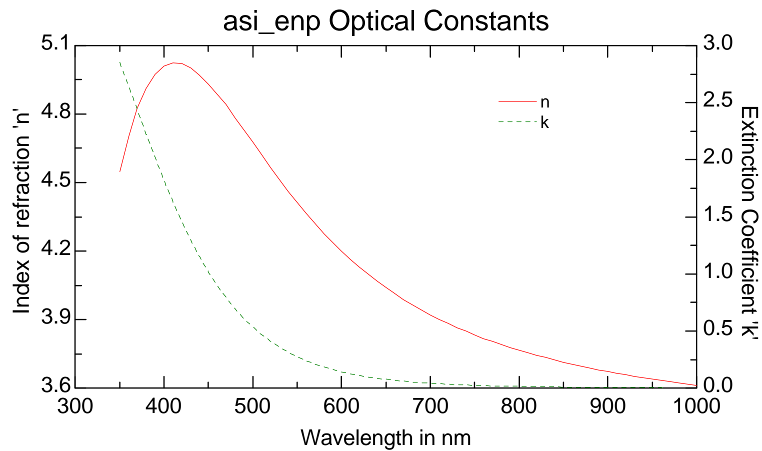




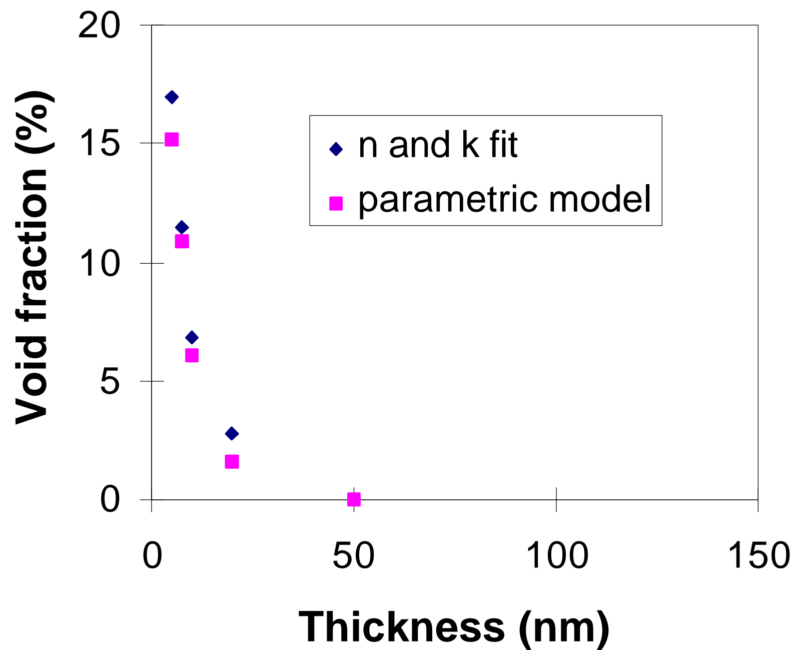
Sample 8:







a-Si nominal thicknes s (nm)	a-SiN thicknes s (nm)	a-Si measure d thicknes s (nm)	Void fraction (%)	top SiO2 thicknes s (nm)
50	-	46.19	-	2.35
20	-	18.64	2.77	1.61
10	-	9.71	6.81	0.898
7.5	-	7.25	11.50	0.117
5	-	5.42	16.97	0
50	274.45	48.28	-	2.69
20	277.28	19.46	2.77	2.14
10	271.22	9.86	6.81	2.3
7.5	272.19	7.86	11.50	1.76
5	273.28	5.61	16.97	2.21



Conclusion:

- Multiple Sample Analysis reduces parameter correlation and allows to analyze even very thin a-Si film regarding thickness and optical constants.
- Decreasing optical density could be expressed by the void fraction as a function of thickness.
- The raising void concentration observed for decreasing film thickness, closely resembles the raising SiH_2/SiH concentration ratio (MIR) and further supports the existence of a low density, hydrogen-rich interface sublayer.
- The void concentration saturates at the null value by definition, for d> 50 nm, and the SiH_2/SiH concentration ration saturates at the bulk value of 0.2 approximately for the same thickness.