Thickness and Optical Constants of Amorphous Carbon Coatings Measured by Spectroscopic Ellipsometry

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Amorphous (a-C) and hydrogenated amorphous carbon (a-C:H) films have many useful physical properties such as hardness, low friction, electrical insulation, chemical inertness, optical transparency, biological compatibility, ability to absorb photons selectively, smoothness, and resistance to wear. For a number of years these technologically attractive properties have drawn tremendous interest towards these coatings. They are widely used to modify surfaces of materials and improve their tribological properties.

Control of their layer thickness and optical constants are important properties for optimising the coatings for R&D and industrial purposes. The characterization of amorphous carbon coatings by spectroscopic ellipsometry enables the simultaneous measurement of these properties as well as further information about surface roughness and the proportion of sp^2 and sp^3 bonds in many cases. Furthermore the technique can provide information about the adherence of the coating where an interface is found between the substrate and the coating.

Properties of diamond and DLC materials

Carbon films with very high hardness, high resistivity and dielectric optical properties, are described as diamond-like carbon or DLC (table 1).

A wide variety of objects are now being coated, ranging from small items, to large dies and moulds. The rapidly expanding uses of DLC films includes decorative/low friction coatings, coating of tools for the high speed machining of aluminium and copper alloys, ceramic washers in mixer taps, guides in textile processing machines, punches/dies, seals, cutting taps and many more. Most of the success has been in applications for magnetic storage media and optical coatings.

	Thin Film		Bulk		
Property	CVD dia	a-C	a-C:H	Diamond	Graphite
Crystal Structure	Cubic a_0=3.561Å	Amorphous Mixed sp^2 and sp^3 bonds	Amorphous sp^3/sp^2	Cubic a_0=3.567Å	Hexagonal a=2.47
Form	Faceted crystals	Smooth or rough	Smooth	Faceted crystals	
Hardness (H_v)	3000-12000	1200-3000	900-3000	7000-10000	
Density (g/cm^3)	2.8-3.5	1.6-2.2	1.2-2.6	3.51	2.26
Refractive Index	-	1.5-3.1	1.6-3.1	2.42	2.15
Electrical Resistivity (Ω/cm)	$>10^{13}$	$>10^{10}$	10^{6}-10^{14}	$>10^{16}$	0.4
Thermal Conductivity (W/m.K)	1100	-	-	2000	3500
Chemical Stability	Inert	Inert	Inert	Inert	Inert
Hydrogen Content (H/C)	-	-	0.25-1	-	-
Growth Rate (µm/hr)	~1	2	5	1000 (Synthetic)	-

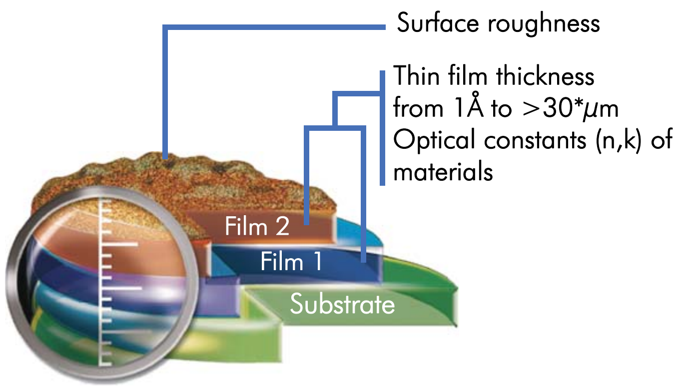
Table 1

What is Spectroscopic Ellipsometry?

Spectroscopic Ellipsometry (SE) is an optical technique mainly used to determine film thickness and optical constants (n,k) for structures composed of single layer or multilayers.

SE is based on the measurement of polarized light. It is non destructive and requires no sample preparation. The technique is very sensitive providing film thickness with angstrom resolution.

The technique is information rich for layer stack description and enables the determination of interface, roughness, film gradient, film anisotropy, etc…



Main properties determined by Spectroscopic Ellipsometry

**Maximal possible thickness for transparent layers*

Optical Characterization of DLC Coatings by Spectroscopic Ellipsometry

Example 1

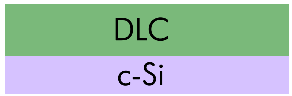
Tetrahedral diamond-like carbon films (ta-C) were deposited by femtosecond pulsed laser deposition (PLD) on c-Si substrates under high vacuum conditions. The aim of this study was to investigate the effect of the laser fluence parameter on the thickness of DLC coatings (and other properties not shown in this note). The application was for implantable biomaterials, with the goal being to improve the wear resistance of the coating deposited on prosthetic hip joints.

Three samples were studied with the deposition conditions indicated below:

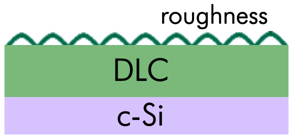
Sample Name	Deposition Time (min)	Laser Fluence ($J.cm^{-2}$)
1	5	2.8
2	5	3.0
3	5	4.2

Measurements were performed using the HORIBA Jobin Yvon UVISEL Spectroscopic Phase Modulated Ellipsometer on the spectral range 1.5-5 eV (827-248 nm).

The first sample was modelled with a single film of DLC, as shown in the model 1, while the 2^{nd} and 3^{rd} sample exhibits a rough overlayer on top of the DLC layer (see models 2 and 3).



Model 1



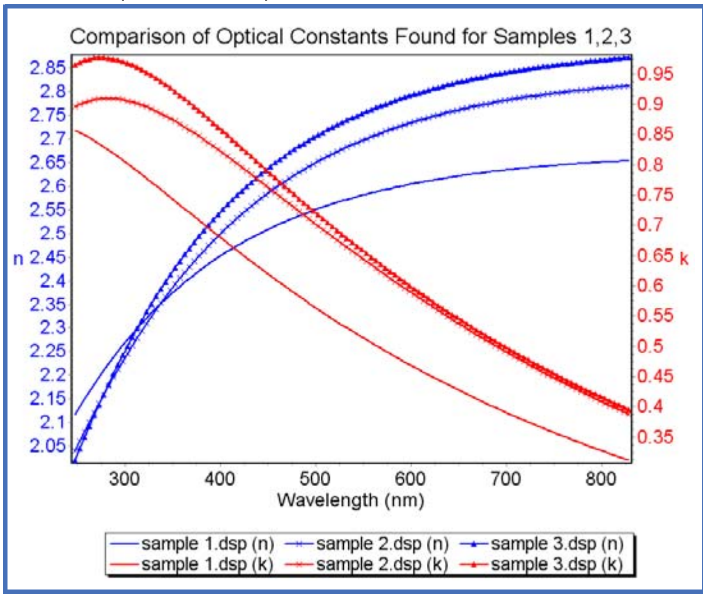
Model 2&3

The results show an increasing DLC film thickness with laser fluence. The same effect was obtained for both refractive indices and extinction coefficients. We can also notice that a rough overlayer appears for samples 2 and 3.

Sample Name	Film Thickness (Å)	Roughness (Å)
1	387	0
2	379	44
3	525	45

Optical constants of the DLC films were modeled with a "New Amorphous" dispersion. The graph below shows the comparison of the optical constants found for the samples 1, 2 and 3.

Comparison of Optical Constants Found for 1, 2, 3

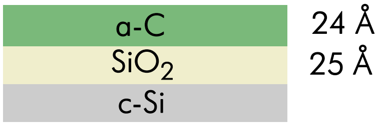


Example 2

The second example shows the results obtained for the characterization of a very thin amorphous carbon film deposited on c-Si substrate.

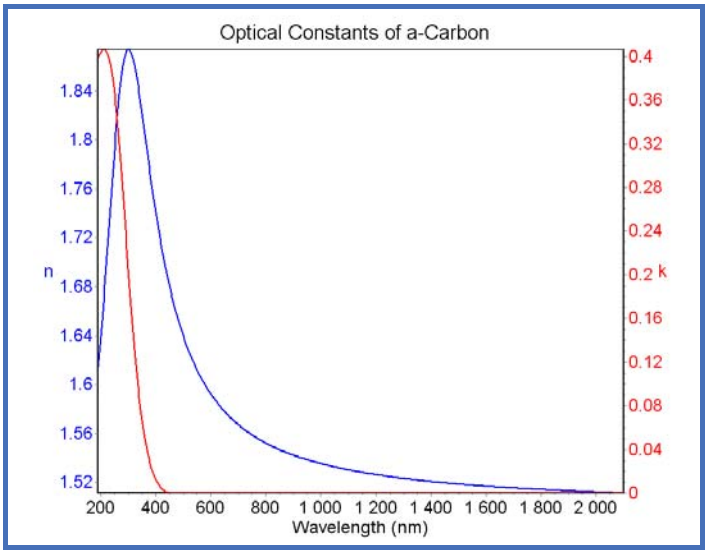
Simultaneous and very accurate determination of film thickness and optical constants of the thin a-C coating was possible using the HORIBA Jobin Yvon UVISEL Spectroscopic Phase Modulated Ellipsometer. Owing to its Phase Modulation Technology and powerful optical design, the UVISEL has superior performance in terms of accuracy and sensitivity compared to other ellipsometers on the market.

The model below has been used to fit perfectly the sample on the extended spectral range from 190 to 2100nm. Note that it includes a native oxide layer between the substrate and the DLC film, and it is very important to determine this layer due to its adhesion properties.



A patented fitting procedure called BLMC included in the DeltaPsi2 software enables the accurate treatment of ultra-thin films.

Optical constants of the amorphous carbon film were determined using the New Amorphous dispersion law.



Conclusion

The UVISEL Spectroscopic Ellipsometer is the ideal tool for reliable film thickness and optical constants characterization of amorphous carbon coatings, even in difficult cases where the film thickness is very thin. Roughness, and interface “adhesion” can also been determined.

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