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Scientific

Application Note

Material Science

Spectroscopic Ellipsometry

SE29

Ellipsometric characterization of doped and undoped crystalline diamond structures

Diamond is known for its hardness, thus it is used in industry in cutting and polishing tools. However this material has several other remarkable properties as optical transparency, chemical stability, thermal and electrical conductivities that could be controlled through the introduction of impurities into the pure phase diamond crystal lattice. Due to these properties, diamond is considered to be attractive for various fields of technology. It can be used as light detector in medical applications, development of implants serving as semi-conductor interfaces with living tissues for biological applications. Furthermore, some of the impurities present in the diamond crystal lattice known as color centers are capable of light emission. Hence, diamond photoluminescent nanoparticles are used as markers in bio-imaging technology as well as detectors of weak magnetic fields at nanometric scale.

In this work, spectroscopic ellipsometry is used to investigate the optical and structural properties of crystalline doped and undoped diamond layers. This information is important for the optimization of the efficiency of these layers when involved in different kinds of devices.

Spectroscopic ellipsometry

Spectroscopic ellipsometry is an optical non destructive technique dedicated to the characterization of the optical and structural properties of thin films. Its principle is based on the analysis of the change of the polarization state of a light beam after it is reflected by the surface of a material. The measured observables are known as Psi(Ψ) and Delta(Δ)[1] . These observables give respectively information regarding the change of amplitude and the phase of the light beam after reflection from a material surface. This double information makes ellipsometry a very sensitive technique that has the ability to measure thicknesses down to a few Angstroms.

Experimental set-up

The experiments have been performed with a HORIBA Scientific UVISEL Spectroscopic Ellipsometer in the wavelength range 190 nm – 2100 nm corresponding to 0.6eV – 6.5eV at 70° angle of incidence. This ellipsometer is based on a phase modulation technology. The signal is modulated at a high frequency (50 kHz) which enables to average more data than ellipsometers based on other technologies. Moreover, it is equipped with two photomultipliers for detection in the UV-VIS range which enables to reach a high sensitivity and signal/noise ratio. The infrared detector is an InGaAs semiconductor detector.

Characterization of Diamond layers by spectroscopic ellipsometry

Crystalline undoped diamond layers on silicon substrate

The first structure characterized in this work consists of a crystalline diamond layer on a silicon substrate.

Figure1 shows the evolution of the experimental observables (Is, Ic) versus wavelength over a range extending from 2100nm to 190nm (0.6eV to 6.5eV).The oscillations of these observables are known as interference fringes and indicate that the material is transparent across the measured range. One can see however on figure 1 that the amplitude of the fringes shows a decay below λ= 400nm. This is due to the increase of the absorption in this range. The model used to describe the structure of this sample is shown in figure 2. It consists in a rough diamond crystalline layer on silicon substrate. The thicknesses obtained for the diamond and roughness layers are respectively T (diamond) = 593nm and T (roughness) = 18nm. In addition, the ellipsometric measurements enable the determination of the optical properties of the diamond layer. The evolution of the refractive index (n) and extinction coefficient (k) are shown in figure 3.

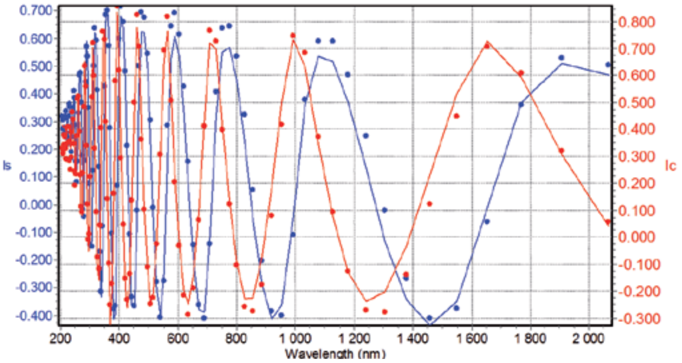

Figure 1

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[1] *These observables are obtained from (Is, Ic) observables in phase modulation ellipsometry*

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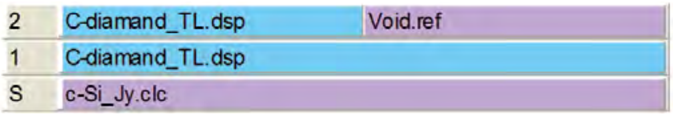

2	C-diamand_TL.dsp	Void.ref
1	C-diamand_TL.dsp	
S	c-Si_Jy.clc	

Figure 2

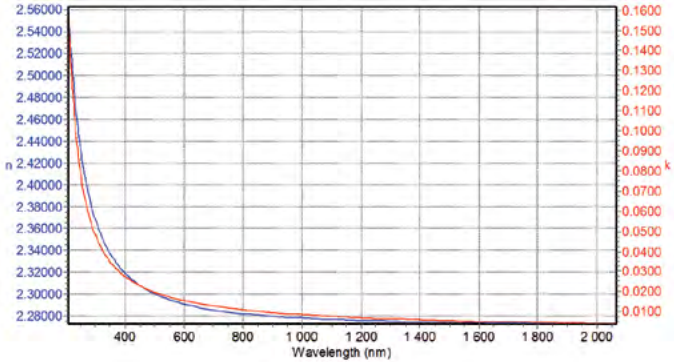

Figure 3

Doped Diamond/Crystalline undoped diamond

The second sample characterized during this investigation consists of a boron doped diamond layer on a crystalline undoped diamond substrate. The optical properties of the substrate were obtained from the previous analysis, and are fixed for this sample. The model used for the structure of this sample is shown in figure 4. The analysis showed clearly that a 43nm interface layer was formed between the substrate and the doped layer. This layer is constituted of 44.7% doped and 55.3% undoped diamond coming respectively from the top and bottom layers. Figure 5 shows the spectral evolution of the experimental (Is,Ic) curves. The thickness obtained for the doped layer was found to be T(doped diamond) = 206nm. Its optical properties are presented in figure 6. This figure shows a significant increase of the absorption through the extinction coefficient by comparison with non doped diamond due to the introduction of boron impurities while the refractive index remains relatively stable.

2	C-diamand.dsp	
1	C-diamand.dsp	C-diamand_TL.dsp
S	C-diamand_TL.dsp	

Figure 4

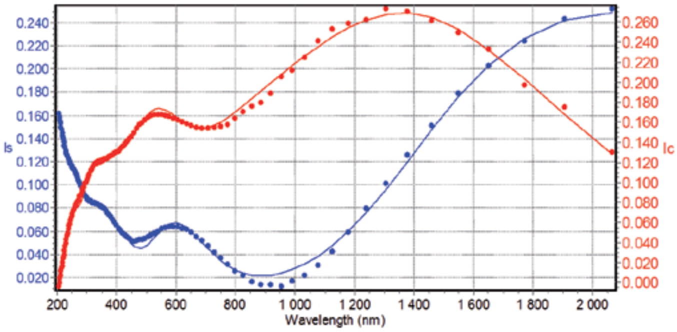

Figure 5

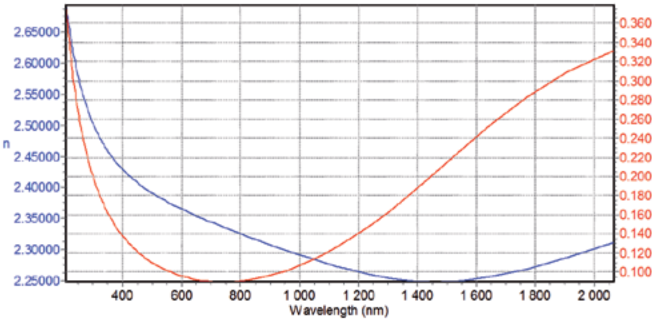

Figure 6

Conclusion

In this work, spectroscopic ellipsometry (SE) was successfully applied to characterize the optical properties and the thicknesses of doped and undoped diamond layers. The sensitivity of this technique enables the doped layer to be distinguished from the undoped one in a sample consisting of a stack of these two layers. Moreover, an interface between the two layers has been detected. This work and others reported previously show clearly that ellipsometry is the technique of choice for the characterization of optical and structural properties of layered materials thanks to its sensitivity and the wide range of information it provides.

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