

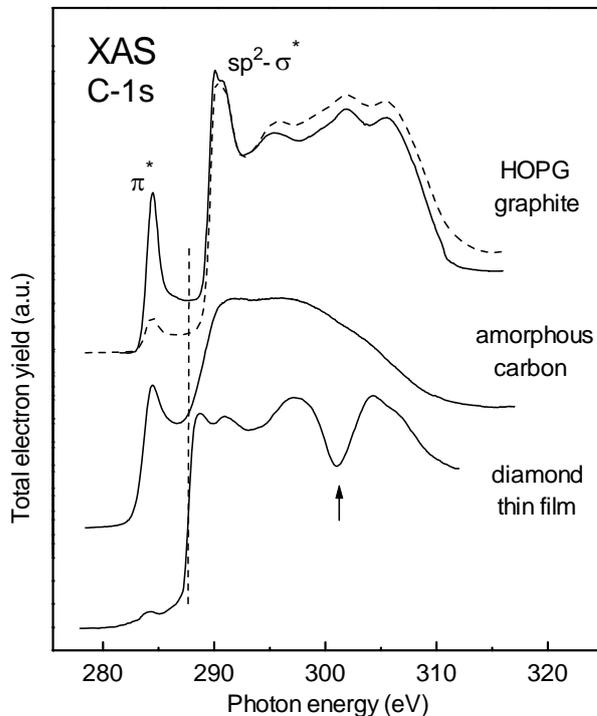
# Determination of diamond thin films quality by X-ray absorption spectroscopy

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The quality of a deposited diamond thin film can be defined as the ratio of diamond to non-diamond carbon in it. X-ray absorption spectroscopy (XAS) allows to distinguish very easily between  $sp^3$ -hybridized carbon and  $sp^2$ -hybridized carbon because the absorption threshold in the first case ( $\sim 290$  eV) lies between  $1s \rightarrow \sigma^*$  and  $1s \rightarrow \pi^*$  transitions in  $sp^2$  carbon (285 eV and 292 eV, respectively). Additionally, the absorption coefficient depends only on the atomic number,  $Z$ , and consequently, no differences in cross section exist between  $sp^3$  carbon and  $sp^2$  carbon. One can take advantage of this fact to perform a quantitative determination of the relative amount of  $sp^3$ - and  $sp^2$ -carbon in order to estimate the quality of diamond thin films.

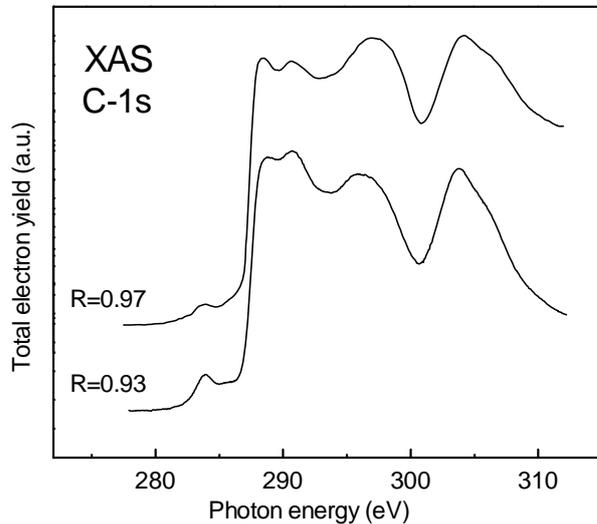
Fig. 1 shows XAS spectra in total electron yield mode of a HOPG graphite reference sample, an amorphous carbon film, and a diamond thin film. All spectra were normalized to the intensity of the incident photon beam. The measurements were performed at the TGM5 monochromator of the Berliner Elektronenspeicherring für Synchrotronstrahlung (BESSY). The graphite sample (top spectrum) was measured at two different polarization angles:  $60^\circ$  (solid line) and  $88^\circ$  (dashed line). Both spectra show all features of other graphite spectra reported in the literature [1]. The spectrum



**Fig. 1:** XAS spectra at the C-1s absorption threshold of graphite, amorphous carbon, and a diamond thin film.

labeled "amorphous carbon" was obtained from a diamond thin film after 5 min sputtering with 3 keV  $Ar^+$  ions, and it is also similar to previous results on amorphous carbon [2]. The bottom spectrum corresponds to a diamond thin film grown by the oxy-acetylene flame method on molybdenum [3]. The most significant spectral features of diamond are present in the spectrum, including the second absolute gap at  $\approx 302$  eV, indicated in the figure by a vertical arrow [2]. The energy resolution employed in the measurements does not allow us to resolve the core exciton at the onset of the  $1s \rightarrow \pi^*$  transitions ( $\approx 288$  eV) [4]. This figure demonstrates the suitability of XAS to distinguish between diamond and non-diamond carbon: the diamond absorption edge lies at the gap between  $\sigma^*$

and  $\sp^*$  states in non-diamond carbon (indicated by the vertical dotted line in the figure). As can be seen in the bottom spectrum, the diamond sample has a small non-diamond component, visible as the small peak at  $\approx 284$  eV. This non-diamond signal originates from amorphous or graphitic carbon present in the sample. The intensity of this feature as compared to that of the leading peak of the diamond signal is a direct indication of the relative amount of non-diamond carbon in the sample.



**Fig. 2:** XAS spectra at the C-1s threshold of two diamond samples with different quality. The parameter R indicates the molar ratio in the combustion of the acetylene.

As an example, XAS spectra of two diamond films of different quality are shown in Fig. 2. The value of R indicates the  $\text{O}_2/\text{C}_2\text{H}_2$  molar ratio used during the acetylene combustion [3]. The lower intensity of the  $\text{sp}^2$  peak in the sample with  $R=0.97$  clearly shows that this sample has a lower non-diamond content. By subtracting the  $\text{sp}^2$  contribution [3], and comparing the corresponding intensity with the intensity of the  $\text{sp}^3$  leading peak, the relative amount of diamond and non-diamond carbon is obtained. Proceeding in this way, we obtain a 5% of non-diamond carbon for the sample with  $R=0.97$ , and a 15% for that with  $R=0.93$ .

In summary, we have shown that X-ray absorption spectroscopy at the C-1s threshold constitutes a very good method to determine the quality of diamond thin films, understood as the ratio of diamond to non-diamond carbon atoms.

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