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Full Length Research Paper

X-ray interactions with potassium carbide

Dikedi P. N.

Wisdom Institute, 67, Kildare road E16 4AJ canning Town, London, England. E-mail: pdikedi@yahoo.co.uk, wisdominstitute@rocketmail.com.

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Soft X-rays are produced owing to high intensity pulsed lasers irradiating solid targets. This project report centres on the interaction of soft X-rays with a multi-electron atom potassium carbide (K_2C_2) in which absorption index, β, and the refractive index decrement, δ, of potassium (K), carbon (C) and potassium carbide (K_2C_2) are calculated. Reflectivties of each material over a range of X-ray photon energy of 10-30000 eV are considered and graphs of reflectivity as a function of photon energy are presented photon energy range for each material is selected to include absorption edge regions. Reflectivity is enhanced when X-rays impinge on K_2C_2 this shows great promises as a possible, suitable target material for nanometre measurement, required in radio biological studies; hence K_2C_2 is considered as a potential optical component for achieving grazing incidence necessary for high resolution X-ray optics.

Key words: X-rays, reflectivity, absorption index, refractive index decrement, grazing incidence.

INTRODUCTION

It is well established that emitted soft X-rays are suited for different applications such as in lithography and biological applications (Mahdieh et al., 2009). The quest for high resolution X-ray optical component for nanometre measurement in radio biological studies led to the report at hand which centres on X-ray interactions with potassium carbide (K_2C_2). This report captures salient cutting edge issues in high resolution X-ray optics, by delving into a study on potassium carbide (K_2C_2) as a target material suitable for cellular probing in radio biological studies. X-rays are produced when fast moving electron beams impinge on metal targets, such that they release radiations characteristic of such targets primary radiation. However, these X-rays may be focused to further impinge on same or other metal targets emitting scattered component and radiation characteristic of the metal target secondary radiation. X-rays interact with matter by absorption and scattering; at the atomic level these interactions are described by scattering factors denoted by f_1 and f_2 in which f_1 describes scattering and f_2 describes absorption.

During absorption, X-ray photon energy is imparted on the absorbing material, resulting to an exponential attenuation of X-ray intensity which may be explained by the following expression:

$$I=I_0e^{-\alpha x} \quad (1)$$

where I_0 denotes initial intensity at distance x=0 and α denotes linear absorption coefficient. Figure 1 shows highly intense X-rays becoming less intense after been scattered by a biological sample.

In this report values of refractive index decrement and absorption index of potassium (K), carbon (C) and potassium carbide are calculated, from which values of reflectivities of these materials are derived over a range of photon energy of 10 to 30000 eV. Graphs of reflectivity as a function of photon energy (selected to include absorption edge for each material) are presented.

Figure 1a explains that the quite intense X-ray passes through a cell or biological sample resulting in a less intense outgoing X-ray. Figure 1b is a schematic of a table top microprobe with potassium carbide coating overlying—or underlying depending on the positioning of the set-up—a silicon membrane surrounded by a silicon nitride frame. With this set-up, micro-probing of biological samples are made possible, and puzzling phenomenon such as the 'bystander effect' could be better understood.

REFRACTIVE INDEX DECREMENT, ABSORPTION COEFFICIENT AND REFLECTIVITY AT NORMAL INCIDENCE

Absorption coefficient, α includes an optical constant, β (Michette, 1999) and is expressed as:

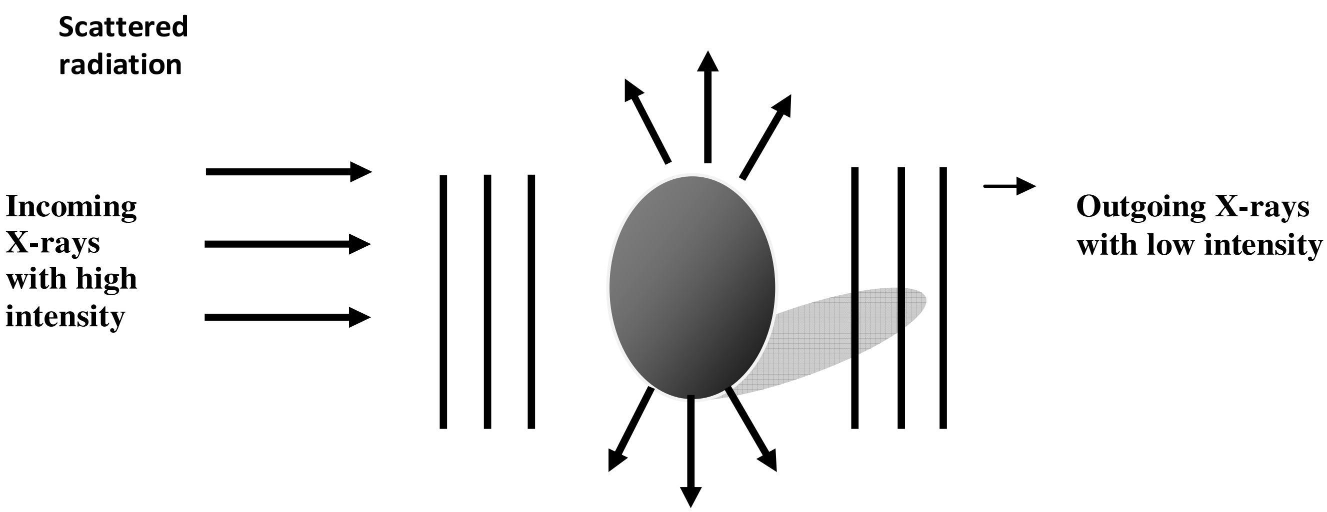

Figure 1a. Scattering of incident X-rays in different directions with less intense radiation after passing through a biological sample.

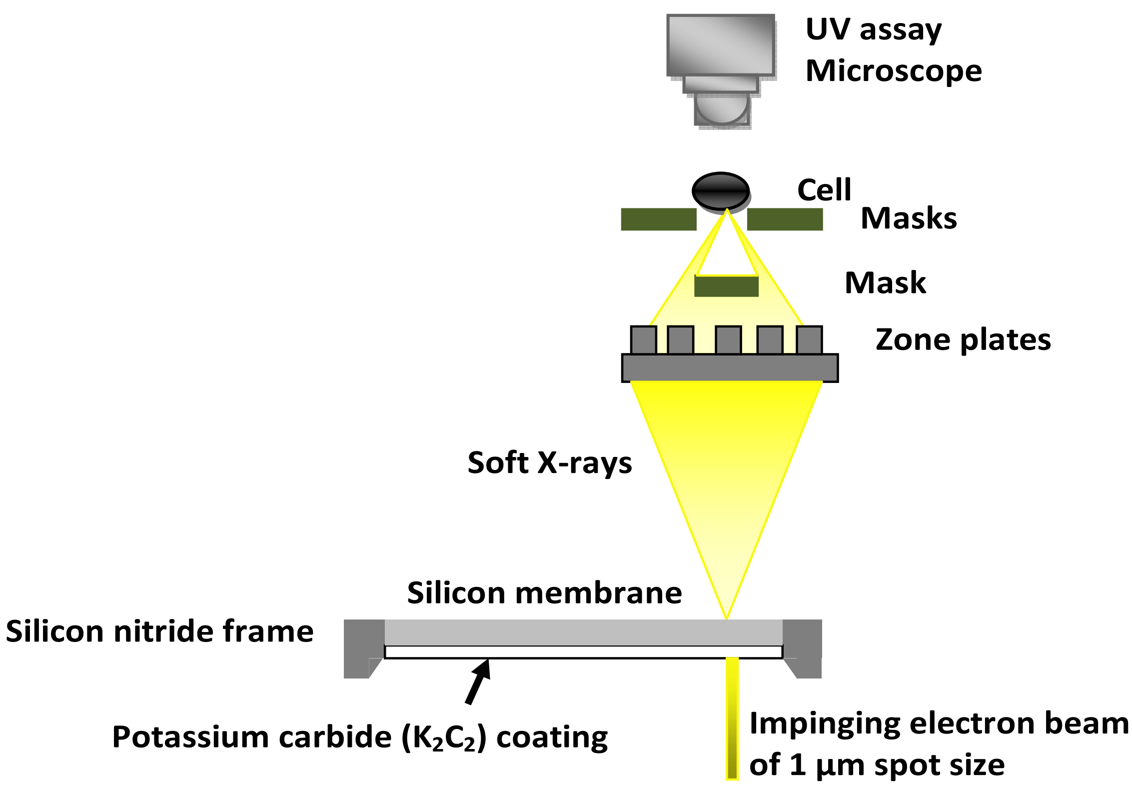

Figure 1b. Schematic of a microprobe with proposed coating of potassium carbide (K_2C_2).

$$\alpha = \frac{4\pi\beta}{\lambda} \tag{2}$$

where β, referred to as the absorption index, may also be expressed as:

$$\beta(\omega) = \frac{Ne^2}{2m_e\varepsilon_0}\frac{f_2(\omega, o)}{\omega^2} \tag{3}$$

where N, is the number of scattering centres, m_e is the mass of an electron, ε_0 is the dielectric constant (Michette, 1999).

Table 1. Shows tabulated values of $\frac{n_a r_e}{2\pi}$ for potassium (K), carbon (C) and potassium carbide (K_2C_2) from which values of optical constants δ and β are derived.

Materials	Potassium(K)	Carbon(C)	Potassium(K_2C_2)
$\frac{n_a r_e}{2\pi}$	5.963×10^{12} Atoms/m^2	5.111×10^{13}atoms/m^2	5.71×10^{13} atoms/m^2

Electronic (or X-ray photon) energy may be imparted or transferred by excitation and ionisation resulting to the production of heat within the target; excitation occurs when some of the electronic or X-ray photon energy is transferred to the target leaving it in a more energetic or excited state and ionisation occurs when X-ray photon energy liberates atomic electrons, which then deposit energy through interactions with other electrons. These interactions are inelastic because the total kinetic energy of the incoming electron (or X-ray photon) and the atom (of target material) are not conserved. The processes involved are Compton effect, photo electric effect and pair production. By considering energy transfer from the incoming X-ray photon to the electron, in which the photon ends up with a lower energy, Compton scattering may be described by:

$$h\nu' = \frac{h\nu}{1 + h\nu(1-\cos\theta) \big/ m_e c^2} \tag{4}$$

where h is Planck's constant, υ is the frequency of the incoming radiation, υ' is the frequency of the outgoing radiation after scattering occurs, m_e is the mass of electron, θ is the scattering angle and c is the speed of light.

During scattering, X-rays interact with atoms, elastically or inelastically; Equation 5 describes an inelastic interaction in which a scattered component has a longer wavelength λ' than that of an incoming X-ray with wavelength denoted by:

$$\lambda' = \lambda + \frac{h}{m_e c}(1-\cos\theta) \tag{5}$$

where δ, referred to as the refractive index decrement is expressed as:

$$\delta(\omega) = \frac{Ne^2}{2m_e\varepsilon_0}\frac{f_1(\omega,0)}{\omega^2} \tag{6}$$

It is also well established that absorption index, β and refractive index decrement, δ may also be expressed in terms of atomic density n_a, electron radius r_e, wavelength of radiation λ and atomic scattering factors f_1 and f_2 (Attwood, 1999, p. 11) as:

$$\beta(\omega) = \frac{n_a r_e \lambda^2}{2\pi} f_2(\omega,0) \tag{7}$$

$$\delta(\omega) = \frac{n_a r_e \lambda^2}{2\pi} f_1(\omega,0) \tag{8}$$

At normal incidence, it is well established (Attwood, 1999, p. 74) that reflectivity, $R\perp$, is related to absorption index, β and refractive index decrement, δ by:

$$R \perp \approx \frac{\delta^2 + \beta^2}{4} \tag{9}$$

Recall,

$$\theta_c = \sqrt{2\delta} \tag{10}$$

$$n = 1 - \delta + i\beta \tag{11}$$

$$\theta_c \alpha \lambda \sqrt{z} \tag{12}$$

where θ_c is critical angle, z is atomic mass of an element, δ is refractive index decrement, β is absorption index and n is refractive index [(Attwood, 1999, p.75; (Yu et al., 1999).

RESULTS AND DISCUSSION

The established values of n_a, for potassium, carbon and potassium carbide (De Laeter and Heumann, 1991) were used; and f_1, f_2 and λ were derived/and calculated from the photon energy range supplied in Henke's table.

Numerically, values of $\frac{n_a r_e}{2\pi}$ have been presented in Table 1 for potassium (K), carbon(C) and potassium carbide (K_2C_2) from which values of absorption index β and refractive index decrement ∂, were calculated using Equation 7 and 8 . Utilizing calculated numerical values for β and ∂; values of reflectivities, R, for potassium (K), carbon (C), and potassium carbide (K_2C_2 or $C_2 K_2$) are

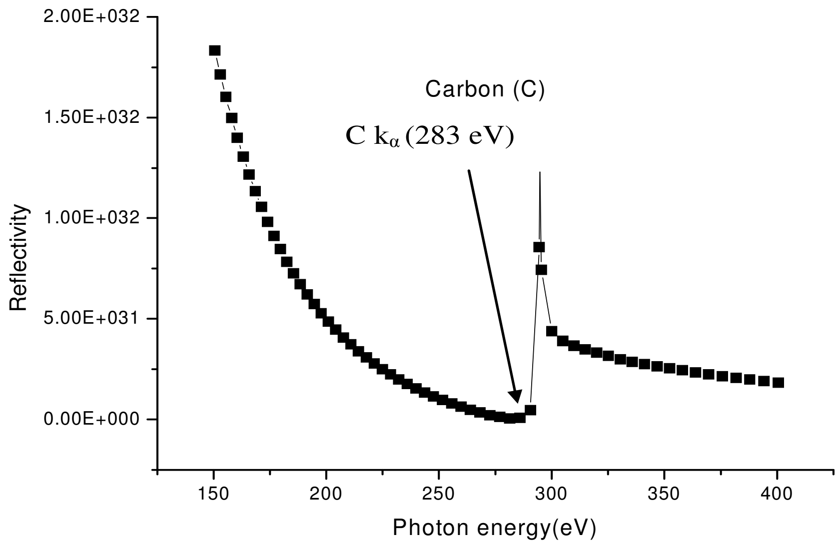

Figure 2(a). Graph of reflectivity as a function of photon energy for the element carbon (C) indicating the absorption edge region.

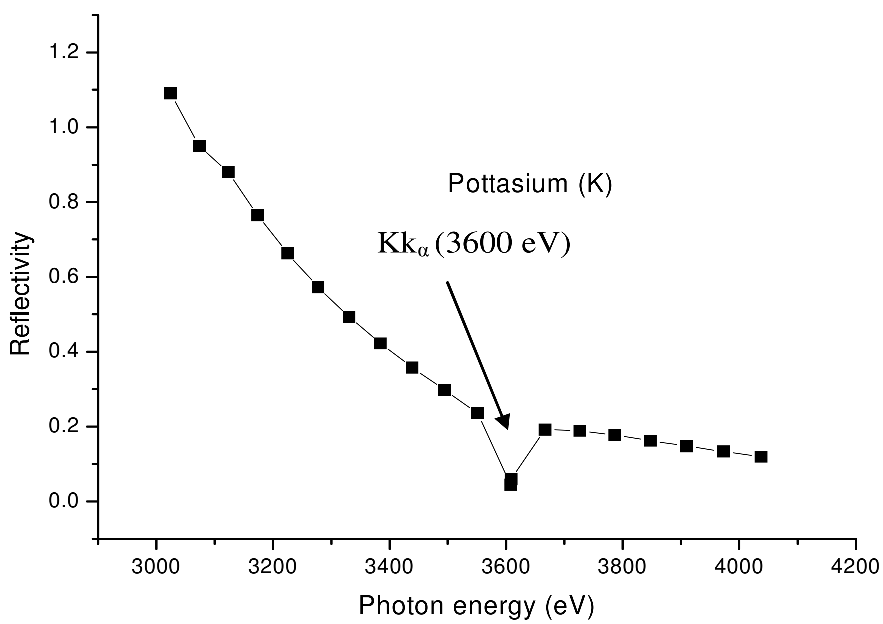

Figure 2(b). Graph of reflectivity as a function of photon energy for potassium (K) which shows sharp anomalous region corresponding to absorption edges.

obtained using Equation 9 from which graphs of reflectivity as a function of photon energy are plotted. Figure 2(a) is a graph of reflectivity as a function of photon energy for the element carbon (C). The region of sharp anomaly indicated by the arrow head corresponds to photon energy values (k_α absorption edge) of 283eV which is in agreement with established k_α absorption edge for carbon (Attwood, 1999, p. 424).

Figure (2b) is a graph of reflectivity as a function of photon energy for potassium (K) where the region of sharp anomaly indicated by the arrow head corresponds to photon energy values (k_α absorption edge) of 3600eV which is in fair agreement with established k_α absorption edge for potassium (Attwood, 1999, p. 424). Potassium carbide, produced by reacting liquid potassium (k) with acetylene takes the form αC_2K_2 at room temperature

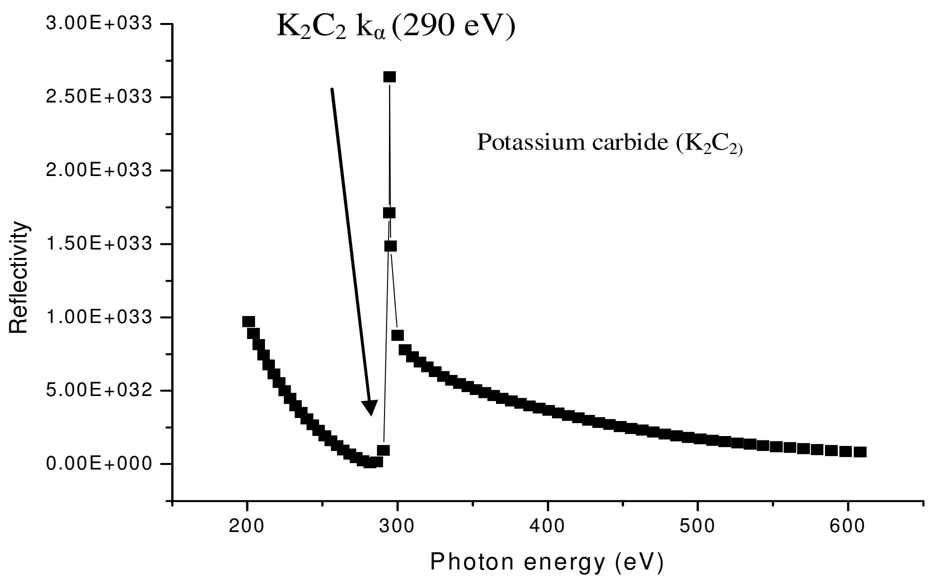

Figure 3. Graph of reflectivity as a function of photon energy for potassium carbide (C_2K_2) which shows sharp anomalous region corresponding to its absorption edge.

and β C_2K_2 at temperatures above 147℃ (Sangster, 2008). Not much has been reported on this compound, which makes it somewhat enigmatic, interpreting the results. A sharp anomaly occurs in Figure 3 at 290eV which is indicative of an absorption edge region. Photon energy ranges for potassium, carbon and potassium carbide in Figures 2(a), 2(b) and 3 have been selected to include absorption edges.

SUMMARY AND CONCLUSIONS

X-ray interactions on multi-electron atom, potassium carbide have been briefly discussed and values of optical constants for potassium, carbon and potassium carbide have been calculated from which reflectivity values for each material have been obtained. Graphs of reflectivity as a function of photon energy for each material have been plotted.

The use of a high z material and long wavelength infers high θc from Equation 12. Equations 9, 10, 11 and 12 explains Figures 2 and 3 in which the conferred enhanced reflectivity of potassium carbide when compared to the reflectivity of carbon was due to a higher molecular mass of potassium carbide. Figures 1, 2 and 3 clearly express the inverse dependence of reflectivity on X-ray photon energy. It is established that reflectively also has an inverse dependence on glancing incidence angles (Attwood, 1999, p. 69). Figures 1, 2 and 3 indicate the effect of absorption edge in reflectivity enhancement. The sharpness of the curve also indicates the occurrence of total external reflection at glancing incidence in which the incoming X-rays do not penetrate the potassium, carbon and potassium carbide but propagate at the interface. Figure 3 shows that reflectivity of k2c2 is enhanced greatly when compared with those of c and k in Figures 1 and 2. This implies that K_2C_2 could be used as an optical component to achieve grazing incidence (Harvey et al., 1988), meaning that high resolution will be attained.

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