Analysis of 80 kV WAXS Measurements with a CdTe Breast Biopsy Diffractometer

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Abstract—**Measurements to test the ability of using a higher kV with a custom built breast biopsy CdTe diffractometer were performed. 80 kV 3.2 mm diameter beams of 3 min duration interrogated 5 mm diameter, 2 to 5 mm thick samples of polymethyl methacrylate (PMMA) and polycarbonate as well as a 5 mm thick water sample. Scattered spectra $N_s(E)$ were measured at θ=6° with a 25 mm^2 × 1 mm thick CdTe detector which subtended a solid angle of detection $\Omega = 4.9\times10^{-5}$ sr at the sample center. The probed momentum transfer *x* range was from 0.3 nm^{-1} to 3.38 nm^{-1}. Linear differential scattering coefficients (μ_s) of water and PMMA were calculated using N_s, an estimate of the incident spectrum (N_0) and a semianalytical model. For μ_s water, N_0 spectra were estimated using N_s from PMMA and polycarbonate plastics of varying thicknesses while only the latter for μ_s PMMA. A detector response function was applied to correct for florescence escape and hole tailing.**

The μ_s of H_2O matched fairly well with literature between 0.42 nm^{-1} < x < 1.68 nm^{-1}, however, above this region discrepancies occurred. No significant effects were observed when using different sample thicknesses to obtain N_0. The results of μ_s PMMA matched well with literature over the whole *x* range. The detector response function did not have a significant effect on the μ_s curves.

It is anticipated that some of the pinhole scatter interacted with the Pb sample holder and then contaminated the Ns spectra. The contamination would be similar for both plastics because of their similar μ values. Regardless, if the μ of the sample being analyzed are similar to those of the sample used to get N_0, the system is capable of probing a wider *x* range using an 80kV beam.

Keywords— **WAXS, CdTe, differential linear scattering coeffcients, diffractometer, breast biopsies**

I. Introduction

Detection of breast cancers is difficult within fibrous breasts because fibrous and cancerous tissue have similar x-ray attenuation properties [1]. Even with advancements in medical imaging technologies, the fundamental limit to diagnosing lesions with primary photons will remain because of the low contrast in μ values. The scattered photons are generally regarded as a nuisance and methods to reduce scatter have been devised such as the use of air gaps and anti-scatter grids. Since most diagnostic imaging is done at low energies (e.g. < 100 keV), the coherent scatter, which is a phenomenon of x-ray diffraction, is a large component of the scattered field. The coherent scatter contains information about tissue structure at the nm scale and could potentially become, if collected effectively, a new source of diagnostic information in the fight against breast cancer.

An important necessary step to advance WAXS in the realm of diagnosis is to measure accurately the scatter signals of the different tissue types. Of particular interest are the signals of fibroglandular and cancerous tissue. To measure the WAXS signals of such tissue is difficult because biopsies of either will most likely contain some fat. A WAXS fat subtraction protocol was therefore devised [2,3] and results obtained with animal tissue [3] were encouraging.

The custom built energy dispersive x-ray CdTe breast biopsy diffractometer system [4] provides means to capture the scattered field in a quantitative fashion thus allowing with the use of a WAXS model the extraction of the differential linear scattering coefficients μ_s of tissue samples. Up-to now WAXS measurements have been done using a 50 kV beam [2-4]. In this work a higher 80 kV beam was used so as to increase the range of momentum transfer $x=1/\lambda \sin(\theta/2)$ that can be probed at a specific scatter angle θ. CdTe detectors are known to have poor hole transport properties and problems with the escape of fluorescence photons. In previous work with 50 kV beams the detector response effects had little impact on the μ_s results. However, due to the use of a higher kV, an analytical model devised for a CZT detector [5] was modified slightly to calculate response functions for the CdTe detector. The mean free paths chosen for electrons and holes were λ_e= 17 cm and λ_h=0.8 cm, respectively.

This work will determine whether background signals caused by using a higher kV beam can be corrected for and whether one needs to incorporate corrections for distorted spectra caused by the detector.

II. Method

A. Apparatus

The diffractometer consists of an x ray cabinet system (Model 43855C [Faxitron Bioptics (LLC), Tucson, AZ], focal spot size: 0.5 mm, kVp: 10-110, mA: 0.3), an ioniza-

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tion chamber, a system of collimators, a sample holder, a CdTe 25 mm^2 × 1 mm thick detector (XR-100T-CdTe, Amptek Inc., Bedford MA) and a system of translation and rotation stages.

A 2 mm diameter 2 mm thick W pinhole was placed 32 cm below the source and 15.7 cm above the sample top. The diameter of the beam at the top of a 5 mm thick sample was 3.2 mm. The samples 5 mm in diameter and 2 to 5 mm thick were placed in a Pb sample holder. The CdTe detector positioned at θ=6° was 42 cm from the sample center and was collimated by a 3 mm diameter aperture 4 cm above the detector. The solid angle subtended by the detector at the sample center was $\Omega_{det} = 4.84 \times 10^{-5}$ sr.

B. Model

For a homogeneous sample of thickness *d* and of attenuation coefficient μ, μ_s can be extracted from a scatter measured spectrum $N_s(E,\theta)$ via [2]

$$\mu_s(E,\theta) = \frac{N_s(E,\theta)}{N_0(E)\Omega_{det}} \frac{\mu(E)C}{(1-e^{-\mu(E)dC})} \times e^{\mu(E)d/\cos\theta} \quad (1)$$

where $C=1-1/\cos\theta$. The model assumed that all scatter events take place along the central vertical line in the sample. The model was also used to estimate the incident spectrum $N_0(E)$ via using a sample with a known μ_s.

C. Materials

Samples of polymethyl methacrylate (PMMA), polycarbonate (polyca) and water were used. The stoichiometric forumlas for each plastic are $C_5H_8O_2$ (PMMA) and $C_{16}H_{14}O_3$ (polyca). Figure 1(a) shows the μ_s curves for each of them evaluated for θ=6°. The plastic data were extracted from Kosanetzky *et al*. [6] data whereas the water curve was obtained using gold standard coherent form factors from Narten [7] and incoherent scattering functions from Hubbell *et al*. [8]. The plastic samples were machined to have 5 mm diameters and thicknesses ranging from 2 to 5 mm. In this work the plastics were used to acquire N_0 spectra so as to allow calculations of μ_s for water. The μ_s of PMMA was also obtained using an N_0 via use of polycarbonate. The μ values shown in Fig. 1(a) were calculated using cross section data for elements of Plechaty et al. [9] and the mixture rule [10].

D. Spectra

Figure 1(b) shows a background spectrum, N_b, obtained with no sample within the Pb holder. The background signal is due to air scatter originating in the column of air irradiated by the primary beam. The spectrum attenuated through a sample was estimated by

$$N_{ba}(E) = N_b(E)e^{-\mu(E)d/2\cos\theta}. \quad (2)$$

The attenuated background spectrum through a 5 mm thick sample of water is also shown in Fig. 1(b). The attenuated backgrounds were subtracted from all N_s spectra. The effects of the response function on background spectra were negligible and only the corrected spectra are shown.

Figure 1(c) shows the N_s spectrum corrected for background for a 5 mm thick water sample. Differences can be seen after the application of the detector response. Low energy signals due to fluorescence were relocated to higher energies.

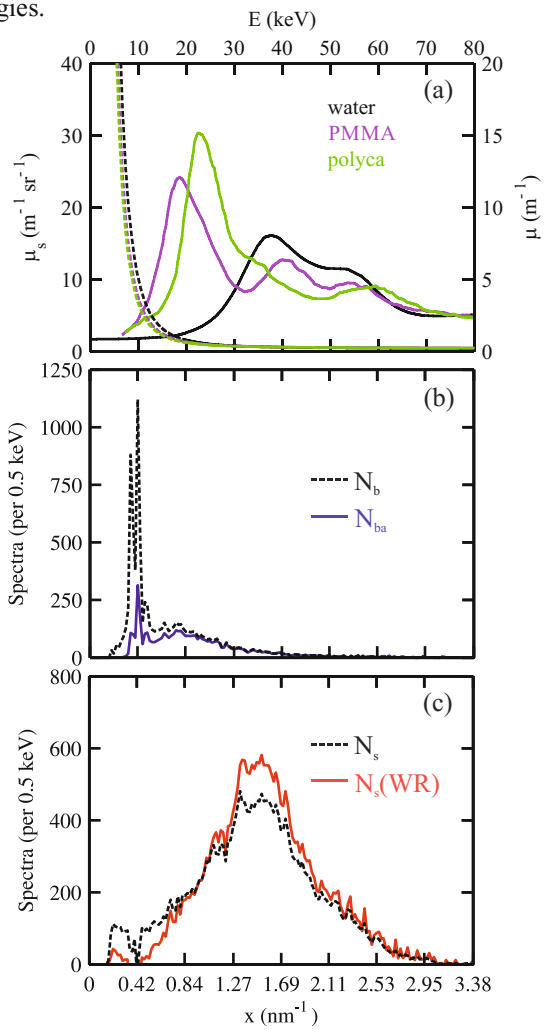

Fig. 1 (a) μ_s (θ=6°) data for plastics [6] and water [7, 8] and their corresponding μ. (b-c) Spectra at θ = 6°: (b) $N_b(E)$ and $N_{ba}(E)$ and (c) $N_s(E)$ for a 5mm thick H_2O sample.

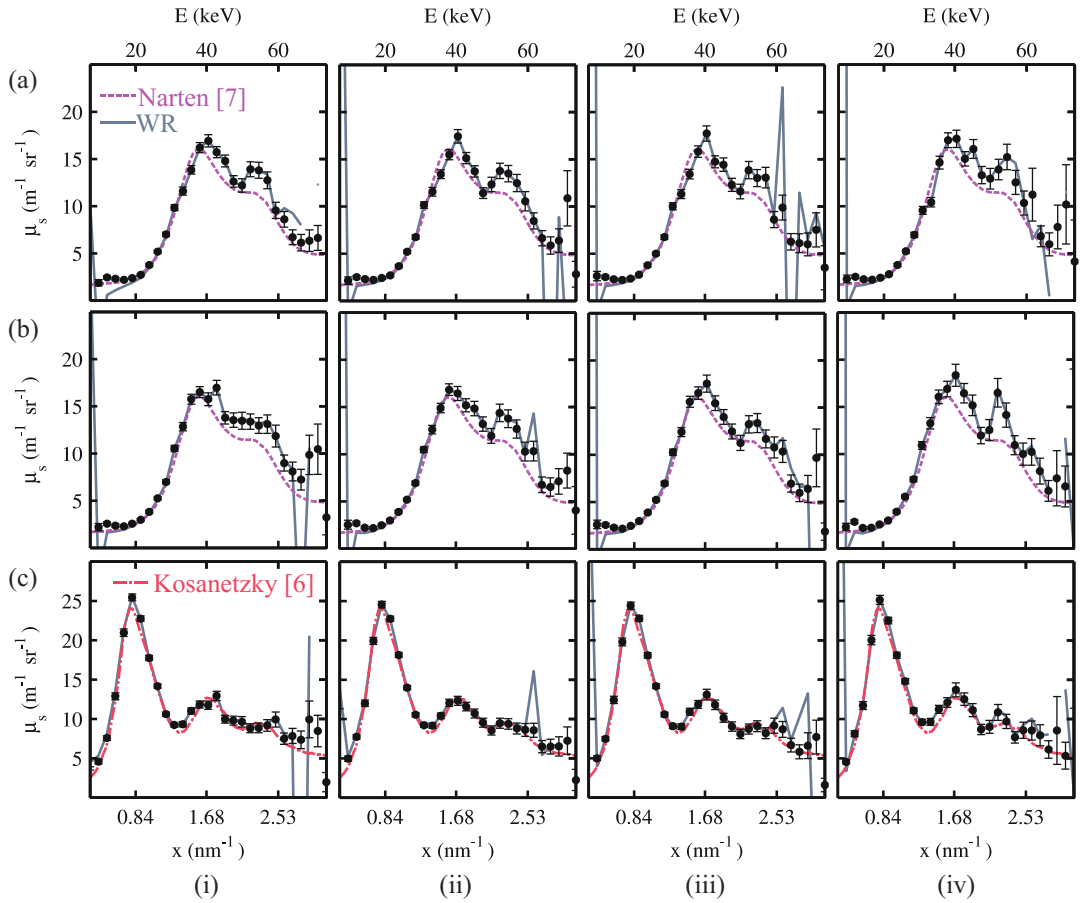

Fig. 2 μ_s at θ= 6° for 5mm H_2O via N_0 (a) PMMA and (b) polycarbonate. (c) μ_s at θ= 6° for 5mm PMMA via N_0 polycarbonate. Sample thicknesses were (i) 5 mm, (ii) 4 mm, (iii) 3 mm, and (iv) 2 mm for the estimations of N_0.

III. Results

Figure 2(a) and 2(b) show μ_s results for H_2O obtained using the $N_s(E)$ scatter spectra shown in Fig. 1 (c). In Fig. 2 (a) N_0 was obtained via PMMA while via polycarbonate in Fig. 2 (b). Panels labeled (i) to (iv) correspond to plastic thicknesses of 5 to 2 mm used for N_0. The μ_s obtained via application of the detector response function (WR) are shown as solid lines.

The measured μ_s data points for H_2O matched well with literature between 0.42 nm^{-1} < x < 1.68 nm^{-1}. However, above this region discrepancies between measured and the gold standard were observed. The data corrected for detector response follows closely with the uncorrected data except at the limits of the μ_s signals (x < 0.42 nm^{-1} and x > 2.53 nm^{-1}). Therefore, the deviations from the gold standard are not a detector issue. The resultant μ_s signals for PMMA matched very well over the entire x-range and no significant differences were observed based on the thickness of plastic used to get N_0. Again the detector response had negligible effects except at the outer *x* limits.

It is anticipated that some of the pinhole scatter interacted with the Pb holder and then contaminated the N_s spectra. The contamination would be similar for both plastics because of their similar μ values.

IV. Conclusion

μ_s results for both H_2O and PMMA were encouraging and insightful. In its current configuration, if the μ of the sample being analyzed are similar to those of the sample used to get N_0, the system is capable of probing a wider *x* range using an 80 kV beam.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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