X-Ray fibre diffraction analysis of 6MV photon-induced *Mimosa pudica*

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Abstract

Mimosa pudica L *(M. pudica)* fibre is a natural fibre with electrically conductive in nature. Because of it"s electro-active sensing nature, it found very interesting among physicists, chemists, biologists, material scientists and technologists. The *M. pudica* fibre was extracted from the stem of the herb by sinking the stem in 10% NaOH solution for one week. The processed fibre was irradiated with 6MV X-ray photon beam with a dose of 20Gy using a medical linear accelerator (LINAC).The effect of fibre structure due to irradiation was investigated using X-ray diffraction (XRD) and scanning electron microscopy (SEM) techniques. In the present report, the structure of *M. pudica* fibre was observed as cellulose-II and is monoclinic in nature. Improvement of fibre orientation due to irradiation was confirmed from both XRD and SEM analysis. The irradiated *M. pudica* fibre shows improved percent of crystallinity along with two new sharp diffraction peaks due to high flux irradiation. In the present work, high energy X-ray photon induced effect and defects on *M. pudica* fibre have been investigated for its implementation in the field of X-ray detector development.

Keywords: MV X-ray photon, LINAC, *Mimosa pudica* fibre, X-ray diffraction, SEM, irradiation

1. INTRODUCTION

The rapid growth of research motivation in bio-inspired engineering stimulated huge interest of scientists and researchers to apply it for technological innovations. By understanding finer mechanism of nature's designs, scientists are bridging the disparity and gap between synthetic and natural arts using scientific methods of investigations and analysis at micro-nano scale. Furthermore, devices emerging from nature's mimicry are looking forward integrating smart sensors, new solar cells and advanced electronics to traditional way of life, defining new era of scientific progress[1].Nature designed biomaterials have structure–functional capabilities that are beyond the reach of manmade materials like silk, leather and wool which are widely used to make clothing [2,3]. If we are successful in

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harnessing bio inspired approaches to smart fabric design which can perform sensing and actuation, we might be able to create intelligent apparel which is currently considered as science fiction. Understanding sensing–actuation mechanism from venous flytrap and touch sensitive *Mimosa pudica* plant (*M. Pudica*), it is possible to design artificial touch sensitive actuators which can be incorporated into apparels [4]. Light sensing mechanism in algae eyespot inspire designing light sensitive apparel which can be worn as optical protective device filtering harmful light rays from electromagnetic spectrum [5]. Camouflage phenomenon, like in Chameleon, put a natural mechanism to design the dream apparel for the military and defence services to hide or make an entity invisible [6]. In addition, design of nano-electronic-fabrics (e-fabrics) is not far from our reach when we will be able to incorporate all fancy e-gadgets such as cellular phone, i-pod and portable computer like chip features in our daily apparel [7]. The plant *M. pudica* shows human muscle's actinmyosin like quick sensing and actuation with its leaf-moving muscle, so-called parvenus which perform touch sensitive hydraulic actuation. Pulvini are swollen part at the base of *M. pudica* leaf stalks or petioles which act as autonomous organ, housing mechano and photoreceptors that enables leave to move in response to external stimuli [8]. Anatomically, all pulvini comprise thick-walled, water conducting vascular tissue, surrounded by thin-walled motor cells. These specialized cells undergo visible swelling and shrinking, actuated by changes in turgor pressure and rapid growth expansion across leaf epidermis involving ion transport. One striking similarity exhibited by pulvinus microstructure with animal joints is their motor cells which bear analogous flexion (flexor cells on upper site) and extension movements (extensor cells on lower site). Increase in turgor pressure and volume caused by the uptake of K^+ ions in the extensor cells lead to full extension of leaf while flexor undergoes a measurable shortening upon stimulation *via* evoked action potential, triggered by touch or sudden darkness. This exhibits one of the remarkable weathering phenomena in plant tissue when touched and exemplifies the fastest plant movements [9]. Development of this methodology is very promising in the fields of soft robotics[10], bio mimetic based monitoring [11], artificial muscles [12] and other bio-inspired devices.

In the present work, high energy X-ray photon induced effect and defects on *M. pudica* fibre have been investigated. It is expected that the study may help to find out the stability of fibre to high-energy X-ray for the design of a windowless X-ray detector.

2. PRINCIPLE

The interaction of photons with matter involves several distinct processes. The relative importance and efficiency of each process is strongly dependent upon the energy of the photons (E_γ) and upon the density and atomic number of the absorbing medium. The electronic system of the atom is the mainly responsible for the absorption of photon. There are three major kinds of interaction mechanism takes place in the electronic system (atom) due to interaction. The maximum kinetic energy of an electron excited due to absorption in the interaction system can be defined as:

$$\left(E_{e^-}\right)_{\max} = \left\{ \begin{array}{l} E_\gamma - \phi_i \quad \textit{Photoelectric effect} \\ \dfrac{2E_\gamma}{2 + \dfrac{m_0 c_2}{E_\gamma}} \quad \textit{Compton effect} \\ E_\gamma - 2m_0 c_2 - E_{e^+} - E_n \quad \textit{Pair production} \end{array} \right\} \tag{1}$$

The eq (1) is the fundamental expression for the X-ray detectors and the symbols have their usual meaning. In very fundamental point of view, when a photon interacts with atom, it may or may not impart some energy to it. In very fundamental point of view, when the photon deflected with no energy transfer is called Rayleigh scattering and is most probable for very low-energy photons. The Compton Effect is usually the predominant type of interaction for medium energy photons (0.3 to 3 MeV). In this process the photon interacts with an atomic electron sufficiently to eject it from orbit, the photon retains a portion of its original energy and continues moving in a new direction. Thus, the Compton Effect has an absorption component and scattering component. The amount of energy lost by the photon can be related to the angle at which the scattered photon travels relative to the original direction of travel. The scattered photon will interact again, since its energy has decreased, it becomes more probable that it will enter into a photoelectric or Rayleigh interaction. The free electron produced by the Compton process may be quite energetic and behave like a beta particle of similar energy, producing secondary ionization and excitation before coming to rest. However, in photoelectric absorption, the most probable fate of a photon having energy slightly higher than the binding energy of atomic electrons. Photoelectric absorption is most important for photons in the range 0.1-1 MeV for materials. But in pair production, photons with energy greater than 1.024 MeV, under the influence of the electromagnetic field of a nucleus, may be converted into electron (0.511MeV) and positron (0.511MeV). Pair production is not very probable, however, until the photon energy exceeds about 5 MeV. The available kinetic energy to be shared by the electron and the positron is the photon energy minus 1.02 MeV, or that energy needed to create the pair. The probability of pair production increases with Z of the absorber and with the photon energy. The above three interaction processes are very important to study the photon-induced modification of materials and design of detectors.

3. EXPERIMENTAL

3.1 MATERIAL

Mimosa pudica L. (sensitive plant) or *sensory papillae* (kingdom: Plantae, Family: Fabaceae, Genus: Mimosa, Species: *M. podica*) is a short-lived, creeping annual or perennial herb commonly found in America (South and central), Tanzania, South Asia, South East Asia and many Pacific Islands near frequent rainfall area. For the present experiment, the plant was collected from the garden of Institute of Physics campus, Bhubaneswar, India*.* The *M. Pudica* fibre was extracted from the stem of the herb by sinking the stem (10cm) in 10% NaOH solution for one week. The treated stem was taken out from the dil. NaOH solution for the careful extraction of its skin. The treated-skin is gently pressed and thoroughly cleaned with running tape water to get the full length (10 cm) of the fibre. Then the fibre was sundried and cut into the required size for different modification and characterisation purposes.

3.2 PHOTON IRRADIATION

X-ray photon of energy 6MV was extract from the medical LINAC of Hemalata Hospital and Research Centre (HHRC), Bhubaneswar, India for the *M. pudica* fibre irradiation work. The fibre was irradiated with a rate of 400 MU/min to attain a dose of 20 Gy. The irradiated fibre then mounted on a fibre mounting holder for X-ray diffraction and electron microscopic analysis.

3.3 CHARACTERIZATION

The X-ray diffraction (XRD) patterns are obtained using a PAN analytical X-ray diffractometer, X'Pert-PRO, employing Bragg-Brentano parafocusing optics. The diffraction patterns were recorded with a step size of 0.02^0 on a 2^0-80^0 range with a scanning rate of 0.0083^0/s. CuKα -radiation from a X-ray tube operated at 45 kV and 40 mA was used. A Xe-gas filled proportional counter was mounted on the arm of the goniometer circle of radius 240 mm to receive diffracted X-ray signal. Experimental control and data acquisition were fully automated through a computer. Fibre sample was mounted on a special type of fibre to form a flat sample of uniform length, breadth and thickness in each test sample for XRD study.

A EVOMA 15, Carl Zeiss SMT, Germany make scanning electron microscope, resolution 3 nm, magnification: < 5-100000 X, was used to investigate the morphology of silver-coated *M. Pudica* fiber. An electron beam of 5kV and 50μA has been used for scanning electron microscopy (SEM) analysis of sample.

4. RESULTS

Heat transmitted through a thin body is much faster than that in comparatively thick one. So the radiation heat is very much sensitive to the natural fibre (micro fibre) of thinner diameter as compared with traditional fibre. Continuous irradiation with comparatively high irradiation photon of 20 Gray or more causes bond breaking or folding of chains. The diffraction patterns obtained from the non-irradiated and irradiated *M.pudica* microfiber are shown in figure 1. The effect of fibre structure due to irradiation was investigated using X-ray diffraction technique. The structure of *M. pudica* fibre was observed as cellulose-II and is monoclinic in nature [13]. Similarly the value of *FWHM* of irradiated sample with respect to virgin fibre is almost equal. It is observed that intensity of maxima peak increases due to irradiation of the samples; at the sometime few new peaks are also observed. The variation of " *d* " values after irradiation is very small. This indicates that there is not much deviation in its structure as shown in Table-1. Again, the azimuth angle *(α)* or average angle of macromolecule disorientation of *M. pudica* fibre is defined in the substance composing the fibers in relation to the meridian or equator as $\alpha = K\,(2\theta_2 - 2\theta_1)/2 = FWHM/2$, where K is the scale factor of diffraction pattern[14]. Hence the helix angle (φ) of the fibre sample can be calculated by simplifying the relation obtained from uni axial spiral orientation ($0^0 < \varphi < 90^0$) as $\varphi = \alpha \cdot Cos\ \theta$, where θ is the Bragg angle. Both azimuth and helix angle are found out to be very small with respect to fibre axis. Also, the above angular values (α and φ) with photon dose remains almost constant. The crystallinity of virgin fibre was found out to be 78%, the value increased to 83% when irradiated at 20Gy.

The scanning electron microscope (SEM) is an important characterising instrument in the study of natural fibers as they give more information on microstructure, fibre diameter, nature of fracture, chemical degradation, fatigue and more others. The SEM micrographs of virgin and 6MV photon-irradiated (20Gy) fibre are shown in figure 2. The SEM micrographs of silver coated fibres at a magnification 500X are analysed. The filament diameter *D*, of the virgin fiber obtained in the range of 10.8 -15.4μm. Usually, natural fibers are highly non-uniform and differ in their diameter from filament to filament in the same fiber. However, it is observed (figure 2(b)) that the filaments become quite uniform with reduced diameter (6-8.7 μm) because of long exposure to radiation (radiation heating). Again, straight line marks on the micrograph as shown in figure 2(b) of the irradiated sample indicates the improvement of fibre crystallinity and uniformity. This can also be observed from the XRD analysis.

Hence, from XRD analysis it has been confirmed that the value of d, *FWHM*, α and φ of the fibre remains unaffected after irradiation with high-energy X-ray photon at high dose (20Gy). Again, improvement of fiber crystallinity and smoothening of filament diameter with reduced value of irradiated *M. pudica* fibre obtained using SEM confirm their suitability for the X-ray detector application. This is very good sign of the material for the development of X-ray detector.

5. CONCLUSION

The *M .pudica* fibre was irradiated with 6MV X-ray photon beam with a dose of 20 Gy using a medical LINAC. The effect of fibre structure due to irradiation was investigated using XRD and SEM techniques. In the present report, the structure of *M. pudica* fibre was observed as cellulose-II and is monoclinic in nature. From the above experimental analysis, It has been confirmed that the crystallographic parameters via, d, *FWHM*, α and φ etc are remain unchanged even after irradiation. Also, the irradiated fibre shows improve crystallinity or strength. The improvement of filament arrangement and reduced D value due to irradiation were also confirmed from the SEM analysis. The above study is a good indication for the design of windowless X-ray detector using *M. pudica* fibre.

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Table 1 X-ray diffraction analysis of *Mimosa pudica* fiber

Sample	2θ (deg.)	I_p (cts.)	I_b (cts.)	*FWHM* (deg.)	*d* (Å)	α (deg.)	φ (deg.)	%C
I(0 Gy)	2.16	161	19	.072	40.9655	0.036	0.036	78%
	14.16	34	23	1.152	6.2486	0.576	0.572	
	16.99	97	10	0.048	5.2152	0.024	0.024	
	22.81	61	46	0.120	2.2857	0.060	0.059	
II(20Gy)	2.15	164	20	0.072	41.0140	0.036	0.036	
	14.16	36	18	1.152	5.8060	0.576	0.527	83%
	16.76	49	17	1.152	5.2866	0.024	0.570	
	22.77	66	12	1.152	3.9024	0.576	0.565	
	24.37	71	11	0.144	3.6501	0.072	0.070	
	38.17	24	3	0.144	2.3561	0.072	0.068	

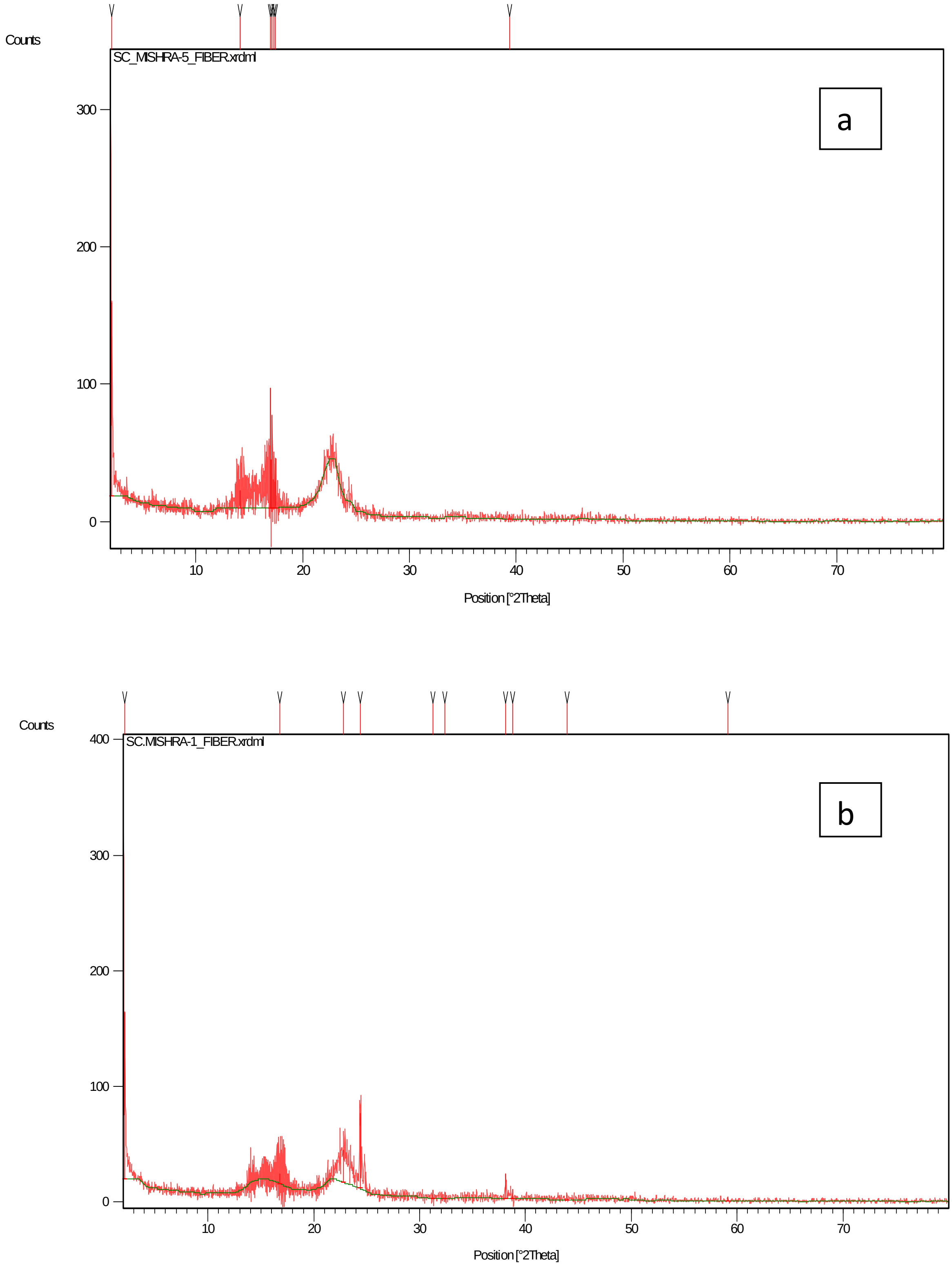

Fig:1 XRD of (a) virgin and (b) irradiated (20 Gee) *M. pudica* Fiber

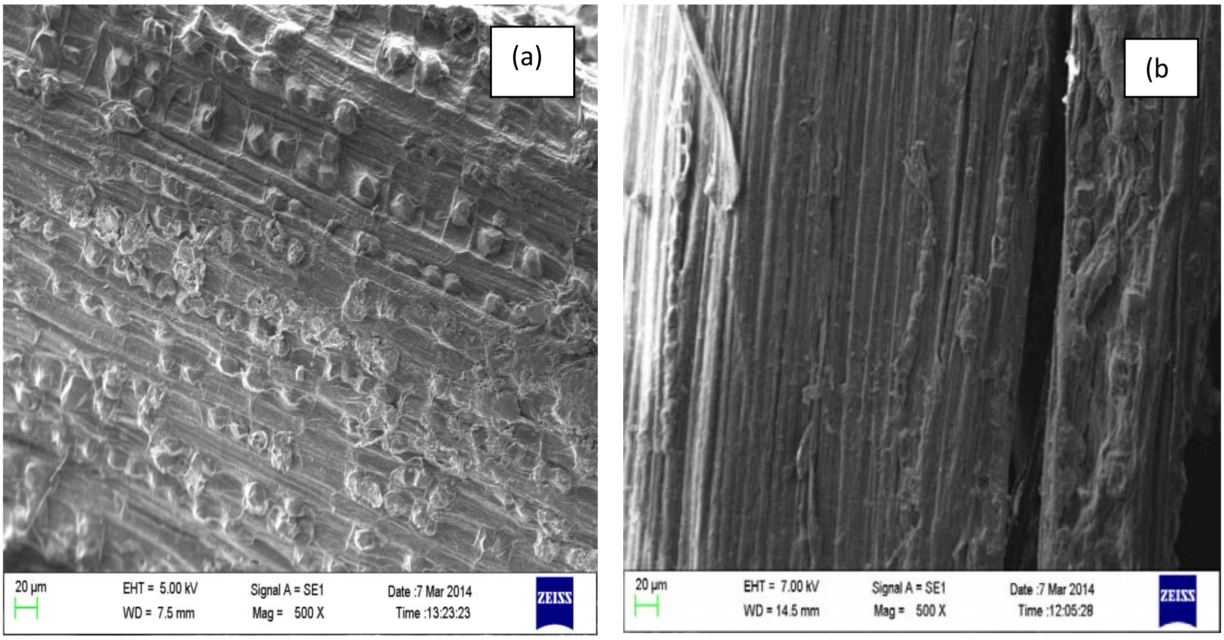

Fig:2 SEM micrograph of (a) virgin and (b) irradiated (20 Gy) *M. pudica* fiber

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