Influence of Low Temperature Argon and Oxygen Plasma Treatment on the Band-gap of Jute

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Abstract— **Low temperature plasma (LTP) treatment is an environmentally friendly surface modification technique. It was applied to biodegradable and ligno-cellulosic jute fibre. In this experimental work two nonpolymerizing gases viz. argon (Ar) and oxygen (O2) plasmas were applied for treatment purposes. With the aim in view, treatment times were 5, 10, 15 and 20 min. and power levels of 50, 75 and 100 W with a flow rate of 0.2 L/min. Ultraviolet Visible (UV-Vis.) spectra of LTP treated jute fibres at various exposure times with different discharge powers were recorded at room temperature in absorption mode using a spectrophotometer in the wavelength range of 200 to 1100 nm. The absorption spectra were recorded for LTP treated jute at various exposure times with different discharge powers. The UV-Vis. spectroscopic analysis reveals that the band gap of jute increases with the increase of exposure times as well as discharge powers. It is also observed from the experiment that band gap of jute when treated by Ar plasma is higher than that of jute treated by O2 plasma.**

Index Terms— **Spectroscopy, Jute fibre, Plasma treatment, Exposure time and Discharge power.**

I. Introduction

In semiconductors and insulators, electrons are confined to a number of bands of energy, and forbidden from other regions. Band gap is the energy difference between the top of the valence band and the bottom of the conduction band. Electrons are able to jump from one band to another. For an electron to jump from a valence band to a conduction band, it requires a specific minimum amount of energy. The required energy differs with different materials [1], [2]. Electrons can gain enough energy to jump to the conduction band by absorbing either a phonon (heat) or a photon (light) [3]. A semiconductor has a very small but nonzero band gap which behaves as an insulator at absolute zero but allows thermal excitation of electrons into its conduction band at temperatures which are below its melting point. In contrast, a material with a large band gap is an insulator. In conductors, the valence and conduction bands may overlap, so they may not have a band gap. There are two types of band gap in semiconductor physics, one is direct band gap and another is indirect band gap. The minimal-energy state in the conduction band, and the maximal-energy state in the valence band, are each characterized by a certain k-vector (momentum vector) in the Brillouin zone. If the k-vectors are the same, it is called a direct gap. If they are different, it is called an indirect gap [4]. For the study of atomic and molecular structure of any matter, measurement of optical properties is very essential. Spectroscopy is the most powerful tool available for the study of atomic and molecular structure and is used in the analysis of a wide range of samples. Spectroscopy is the branch of science dealing with the study of interaction of electromagnetic radiation with matter [5]. When a ray of monochromatic light, which is composed of photons of a range of wavelengths, incident perpendicularly on the surface of the jute sample a fraction of the photons, is reflected from the surface and the remaining photons enter into the sample. Some of these absorbed within the sample and some transit the sample, emerge from the far side and are lost. Most of those photons that are absorbed in the sample give rise to electron-hole pairs [6], [7].

In the past few years interest has increased in the use of Low Temperature Plasma (LTP) technique which is a promising approach for surface modifications of human made as well as natural fibres. Plasmas are ionized gases. An ionized gas consists mainly of positively charged molecules or atoms and negatively charged electrons. A gaseous complex that may be composed of electrons, ions of both polarity, gas atoms and molecules in the ground or any higher state of any form of excitation as well as of light quanta is referred to as plasma [8], [9]. The ionization degree can vary from 100 % (fully ionized gases) to very low values (partially ionized gases). The presence of a non-negligible number of charge carriers makes the plasma electrically conductive so that it responds strongly to electromagnetic fields. Plasma therefore has properties quite unlike those of solids, liquids or gases and is considered to be a distinct state of matter. As a type of environment friendly physical surface modification technology, LTP treatment is one of the methods used to modify surfaces in a dry process. Advantages of this technique, compared to a conventional wet process, are: (i) because of the very thin treatment layer, only the surface is modified without interfering the bulk properties and (ii) the process is simpler, fewer steps and less time are required, involving no chemicals [10].

The study of polymers has become an expanding field of scientific and industrial interest. Naturally occurring and

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synthetic polymers are found very useful to mankind. Jute fibre lies in the category of naturally occurring polymers, which is abundantly available in Bangladesh [11].

Jute is a golden fibre as well as a major cash crop of Bangladesh. A great advantage of jute fibre is that, it is environment friendly natural fibre. This natural fibre earns a lot of foreign currency by its export and its various products. Jute plays a very important role in the socio-economic activities of Bangladesh. Prospect for producing a wide variety of jute products and thus maximum utilisation of jute in the possible fields of textile sectors as well as electrical equipment is very encouraging. At present jute is facing tough competition from the convenient and competitive synthetics counter parts in world market. The only way to save jute is through its uses in various diversified ways [12], [13]. Hence for better performability and to explore diverse use of jute study of optical properties of jute fibre is very important. From this study we found the values of optical band gap of both raw and LTP treated jute fibres. Also from these values of band gap one can use jute fibre in power transformer, rotating machines, circuit breakers, electrical cables, power capacitors and many electronic as well as electromechanical equipment simultaneously with other materials having the same band gap.

II. MATERIALS AND METHODS

A. *Low Temperature Plasma Treatment*

Jute fibres (Corchorus Olitorius or Tossa jute) were collected from the local market in Bangladesh. The fibres were introduced into a bell jar type capacitively coupled glow discharge reactor as shown in figure 1.

Fig. 1 Schematic diagram of jute fibre and position of it in the glow discharge reactor

To sustain a glow discharge i.e. for getting proper and uniform plasma, the conductive electrodes are separated 0.035 m apart from each other. In order to exposed all through uniform LTP treatment on the samples surface, the fibres (length of each fibre: 0.08 m) were inserted in between the two metallic electrodes by a carrier. After placing jute fibres between pair of electrodes, the glow discharge chamber was evacuated by a rotary pump at a pressure of 1.33 Pa. Ar was considered as plasma gas for treating the jute fibre. In all treatments, both process gases were introduced separately into the reaction chamber by a flowmeter at a flow rate of 0.2 L/min. which is maintained by a needle valve. The discharge powers were adjusted at 50, 75 and 100 W at a line frequency of 50 Hz with the duration of exposure times of LTP treatment of fibres were 5, 10, 15 and 20 min. Figure 2 shows a flow chart of a plasma treatment system which was used in this experiment.

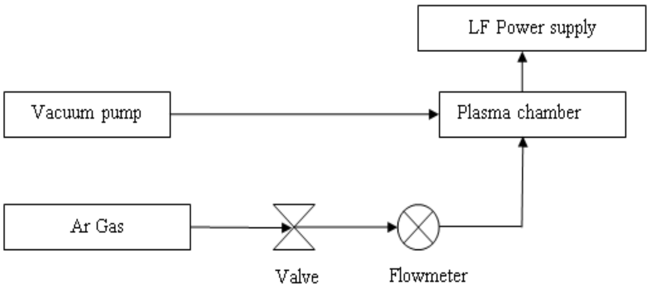

Fig. 2 Flow chart of the plasma treatment set-up

After plasma treatment has been finished, and the vacuum chamber was vented, jute samples were then removed and handled carefully in order to avoid possible surface contamination to the fibres. Later, the plasma treated fibres were immediately placed into a desiccator with the silica gel.

B. *Sample Preparation*

In preparing the samples, both raw and plasma treated jute fibres were cut into small pieces of sizes of about 1.0-2.0 mm. By mortar and pestle these small pieces of jute were ground, crushed and mixed in order to convert into powder form. Finally, the jute powders were seived by a very fine and thin net to make the powder finer. The powdered form jute of about 200 mg. was then put in a specially prepared high-pressure die. In order to make the tablets from jute powder, a high pressure (14000 psi) was applied by a hydraulic press (Model: X30659, 0-16000 psi, Mold Pressure, P.S.I: 1" and 5/4" Mold, Will Corporation, NY, USA). The diameter and the thickness of each equipped tablet was 13.5 and 1.5 mm respectively. In this way twenty five types tablets (one tablet was for raw jute and another twelve were for LTP treated jute) were prepared with treated jute samples of different discharge powers and exposure times. All the tablets were oven-dried at 100 °C for 20 minutes before characterization of the samples.

C. *Ultraviolet visible spectroscopic analysis*

The UV-Vis. spectra of raw jute and plasma-treated jute fibres at various exposure times with different discharge powers were recorded at room temperature in absorption mode using a Shimadzu UV-1601 spectrophotometer (Shimadzu, Tokyo, Japan), in the wavelength range of 200 to 1100 nm. The absorption spectra were recorded both for raw jute and plasma treated jute (tablet, thickness: 1.50 mm) at various exposure times with different discharge powers. Figure 3 shows the overview of UV- Vis. spectrophotometer which was used in this experiment.

Fig. 3 A photograph of UV- Vis. Spectrophotometer

III. RESULTS

Absorbance at different wavelengths were calculated for both raw jute and LTP treated jute with Ar and O_2 gases at various discharge powers (50, 75 and 100 W) and exposure times (5, 10, 15 and 20 min.). The absorption coefficient, α, was calculated from the absorbance data using the relation $\alpha = 2.303(A/d)$ [14], where A is the absorbance and d is the thickness of the jute tablet. The spectral dependence of α as a function of photon energy, hν (where, h is the Planck constant and ν is the frequency, $\nu = c/\lambda$, where, c is the velocity of light and λ is the wavelength of light) helps to measure the band gap E_g. The optical band gap, E_g, is determined from the intercept of the linear part of the absorption coefficient, α vs. photon energy, hν curves extrapolated to zero α in the energy axis. In this way, the values of E_g are obtained for the raw jute and all LTP treated jute samples.

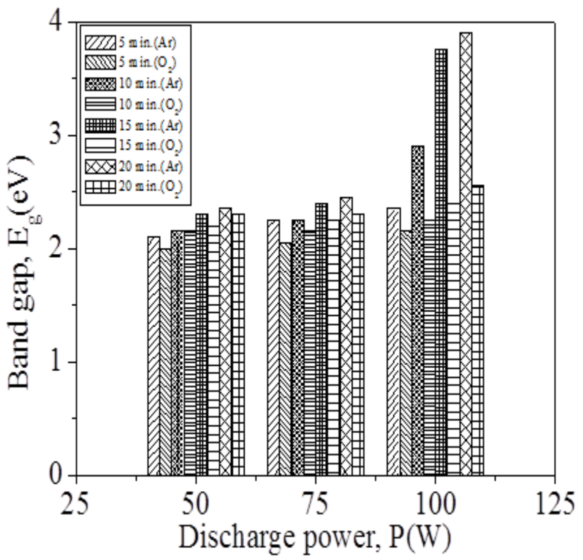

Fig. 4 Band gap vs. discharge power of jute in Ar and O_2 plasmas at different times

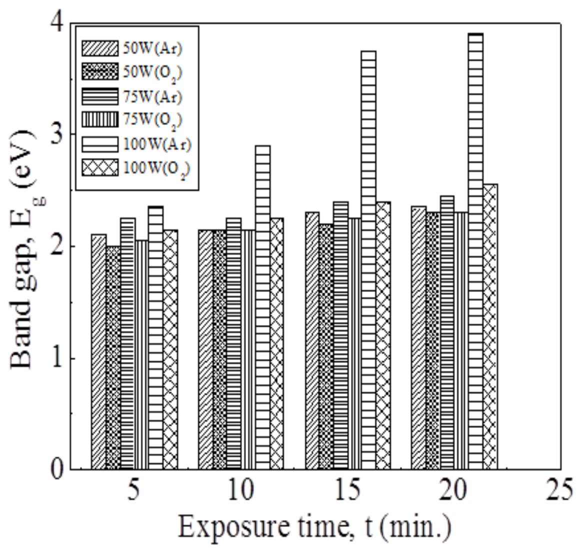

Fig. 5 Band gap vs. treatment time of jute in Ar and O_2 plasmas at different discharge powers

Figure 4 shows the band gap vs. discharge power at various exposure times and the figure 5 shows the band gap vs. treatment time at various discharge power of LTP treated jute.

IV. DISCUSSION

It is seen from the figures 4 (band gap vs. discharge power) and 5 (band gap vs. exposure time) that band gap, E_g of jute increases with the increase of both exposure time as well as discharge power. The reasons behind the increase of E_g with the increase of exposure time and discharge power may be explained as follows:

Chemically jute possesses high content of semicrystalline and amorphous materials, such as cellulose, hemicellulose and lignin. Moreover, due to the presence of the hydroxyl and carboxyl groups on the fibre surface and in the amorphous region, the jute fibres can absorb moisture from the atmosphere under standard conditions of temperature and pressure [15].Therefore, the jute are hygroscopic as well as hydrophilic in nature. When jute is exposed to LTP condition, energetic charged particles inside the plasma are able to interact chemically with the surface to be treated. Such interactions can also affect the material properties and the moisture content of the treated jute decreases due to the surface modification of the jute fibres. In the LTP process, the water (H_2O) dissociates into H and OH species by energetic gaseous ion bombardment. The temperature sensitive jute were dried more effectively in plasma without damaging its constituents and also improved the crystallinity of jute [16]. Therefore, E_g increases with an increase of exposure times and discharge powers. It is also seen from the figures 4 and 5 that at various discharge powers and exposure times, the E_g of jute treated by O_2 plasma is lower than that of jute treated by Ar plasma. This may due to the oxidation of the surface of lignin and hemicellulose when the jute treated by O_2 plasma. In addition, cellulose-based jute are intrinsically polar in nature owing to the presence of hydroxyl and carboxyl groups in their structure [17]. The O_2 plasma treatment of the jute may lead to an increase in the polar component mainly due to the increase of the content of hydroxyl and carboxyl groups. Thus, the jute treated by O_2 plasma is relatively less dry compared to the Ar plasma treated jute. That is why E_g of jute treated by O_2 plasma is lower than that of Ag plasma.

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