# Studies on Loss-tangent of Argon and Oxygen Plasmas Treated Jute

**Md. Anisuzzaman Rassel, Md. Masroor Anwer**

*Abstract*— Low temperature plasma (LTP) treatment, a kind of environmentally friendly surface modification technique, was applied to biodegradable and ligno-cellulosic jute fibre with the use of two non polymerizing gases, namely argon (Ar) and oxygen (O2) at various discharge power levels of 50, 75 and 100 W and exposure times 5, 10, 15 and 20 min. with a flow rate of 0.2 L/min. Dielectric loss quantifies a dielectric materials inherent dissipation of electromagnetic energy properties of both raw and low temperature Ar and O2 plasma treated jute were studied at various discharge power levels and exposure times. The dependence of the tanδ with frequency at different treatment times and discharge powers for all the jute samples show small relaxation peaks at the very low frequency region. The values of tanδ decrease with the increases of both plasma treatment times and discharge powers. Also, the relaxation peaks shifted to the higher frequency region as the plasma treatment times as well as discharge power increases. At low frequencies relaxation peaks indicates the possibility for the interfacial polarization.

*Index Terms*— Low temperature plasma treatment, Loss-tangent, Relaxation peaks, Exposure time and Discharge power.

## I. INTRODUCTION

The dielectric loss tangent is defined by the angle between the capacitor's impedance vector and the negative reactive axis, as illustrated in the diagram to the right [1], [2]. It determines the lossiness of the medium. Similar to dielectric constant, low loss tangents result in a "fast" substrate while large loss tangents result in a "slow" substrate. Dielectric loss quantifies a dielectric material's inherent dissipation of electromagnetic energy (e.g. heat). It can be parameterized in terms of either the loss angle $\delta$ or the corresponding loss tangent tan $\delta$. Both refer to the phasor in the complex plane whose real and imaginary parts are the resistive (lossy) component of an electromagnetic field and its reactive (lossless) counterpart [3], [4]. A capacitor essentially consists of two conducting surfaces separated by a layer of an insulating medium called dielectric. The conducting surfaces may be in the form of either circular (as in this experimental work) or rectangular plates or be of spherical or cylindrical shape. The purpose of a capacitor is to store electrical energy by electrostatic stress in the dielectric. A dielectric increases the charge storage capacity of a capacitor by neutralizing some of the free charges, which would otherwise contribute to the potential difference opposing the battery voltage [5], [6]. As a result, more charge can flow into the capacitor, which then has an increased storage capacity given by $\varepsilon_r C_0$, where,

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$C_0$ is the original capacity in air and $\varepsilon_r$ is the dielectric constant. When a varying electric field is applied to a dielectric material some energy is dissipated as heat known as dielectric loss [7]. As for example, when a capacitor is incorporated in an alternating current circuit it alternately charged and discharged in each half cycle. When the polarity is changed the charges must be displaced through the dielectric first in one direction and then in the other, and overcoming the opposition that they encounter leads to a production of heat through dielectric loss, a characteristic that must be considered when applying capacitors to electric circuits, such as those in radio and television receivers. Dielectric losses depend on frequency and the dielectric material. **Dielectric loss factor which is r**elated to the complex relative permittivity is a combination of the loss of energy in a dielectric material through conduction, slow polarization currents and other dissipative phenomena. The peak value for a dielectric with no direct-current conductivity occurs at the relaxation frequency, which is temperature related [8], [9].

Solid dielectrics can be broadly classified into the following groups: (i) Organic materials, (ii) Inorganic materials, (iii) Synthetic materials. Atomic or molecular point of view, all dielectrics fall into the following three groups: (a) Non-polar materials, (b) Polar materials, (c) Dipolar materials [10]. Dielectric relaxation as a whole is the result of the movement of dipoles (dipole relaxation) and electric charges (ionic relaxation) in an applied alternating field, and is usually observed in the frequency range $10^2$-$10^{10}$ Hz. Relaxation mechanisms are relatively slow compared to resonant electronic transitions or molecular vibrations, which usually have frequencies above $10^{12}$ Hz. The dielectric constant of the material is higher, as greater the polarizability of the molecules. Dielectric relaxation refers to the relaxation response of a dielectric medium to an external electric field of microwave frequencies. This relaxation is often described in terms of permittivity as a function of frequency, which can, for ideal systems, be described by the Debye equation [11], [12].

It is conventional to describe the performance of a capacitor at a certain frequency and temperature in terms of its loss angle, $\delta$, which is the phase angle between the total current, i, and the purely quadrature component $i_C$. A real capacitor has a lumped element model of a lossless ideal capacitor in series with an equivalent series resistance (ESR). The loss tangent is defined by the angle between the capacitor's impedance vector and the negative reactive axis [13], [14].

Plasmas are ionized gases. An ionized gas consists mainly of positively charged molecules or atoms and negatively charged electrons [15], [16]. 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. 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 [17].

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 [18], [19]. 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 thermal sectors are very encouraging. At present jute is facing tough competition from the convenient and competitive synthetics counter parts in the world market. The only way to save jute is through its uses in various diversified ways [20]. Hence for better performability and to explore diverse use of jute, study of Loss-tangent by different plasma gases treated jute fibre is very important.

## 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.
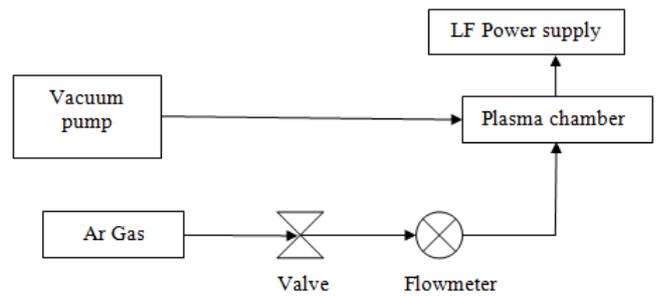


Fig. 2 Flow chart of the plasma treatment set-up

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. Dielectric loss-tangent measurements

The dielectric measurements were carried out at room temperature using a Precision Impedance Analyzer (Model: 6500B, Wayne Kerr, Made in UK) (figure 3) over the frequency range 100 Hz-120 MHz. The frequency dependent values of parallel capacitance ($C_p$) and conductance ($G_p$) of the tablet formed jute samples were noted directly at different frequencies at room temperature.
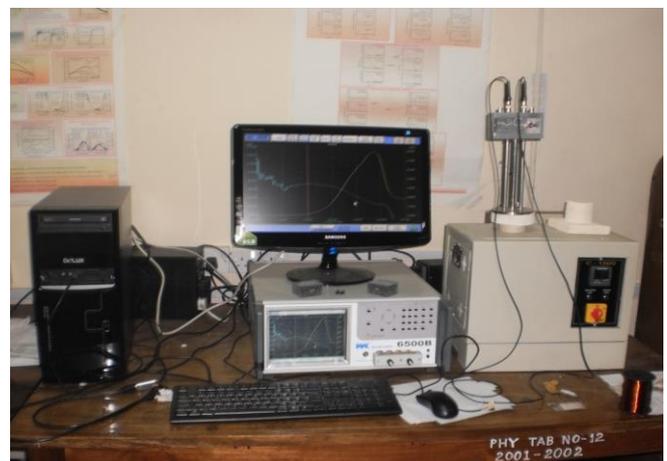


Fig. 3  Arrangement for AC measurement

## Calculation of Dielectric loss-tangent of different types of jute samples

**Dielectric loss-tangent:** The dielectric loss-tangent (tanδ) can also be calculated using the relation

$$\tan \delta = \frac{G_p}{2\pi f C_p}$$

where, $C_p$ and $G_p$ are the parallel capacitance (in F) and parallel conductance (in Siemens) respectively, f is the applied frequency.

### III. RESULTS

**Variation of dielectric loss-tangent with frequency**
Figure 4 shows the variation of dielectric loss-tangent with applied frequency of raw jute and LTP treated jute with different gases, exposure times and discharge powers.
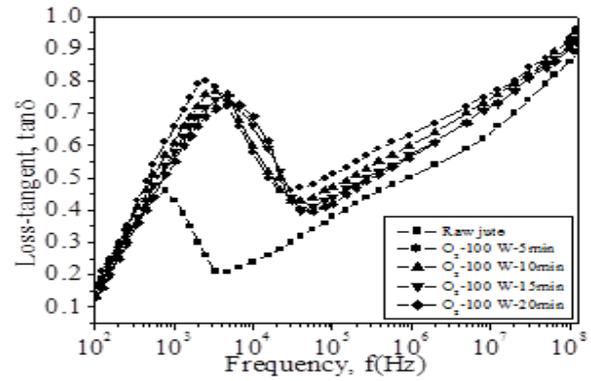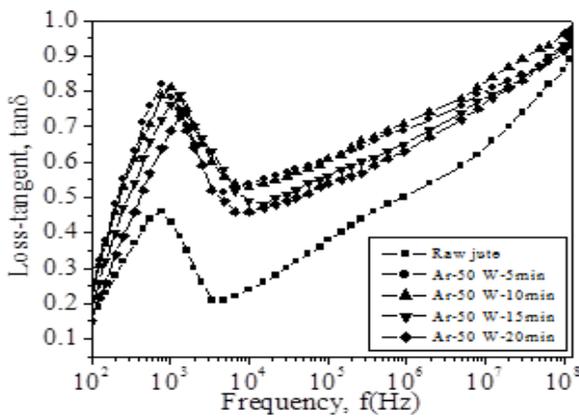


Fig. 4(a): Variation of loss-tangent with frequency of raw and LTP treated jute of various treatment times and discharge powers for Ar and $O_2$ plasmas.
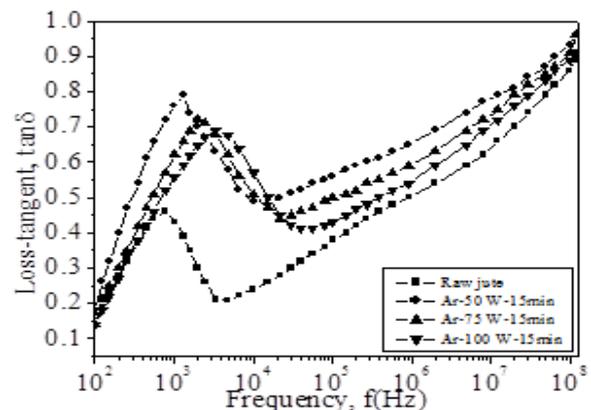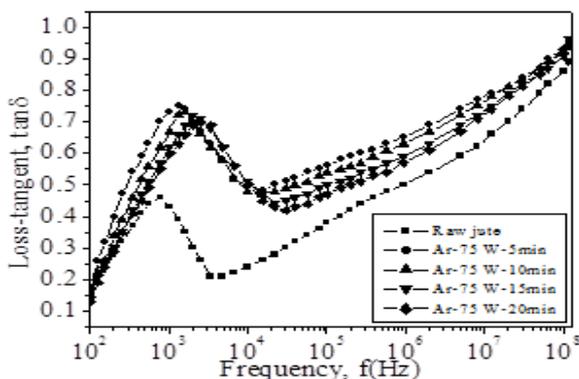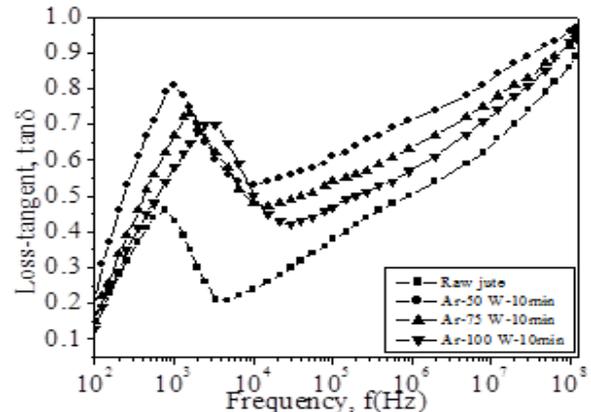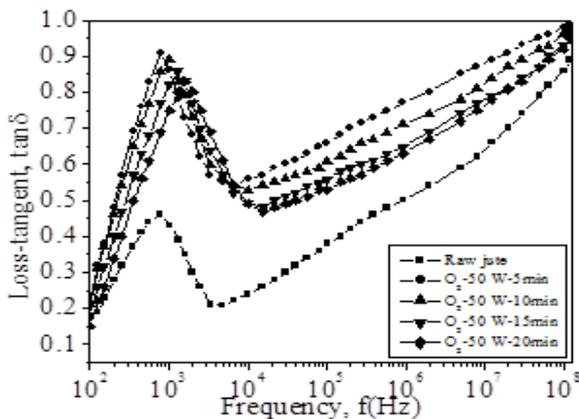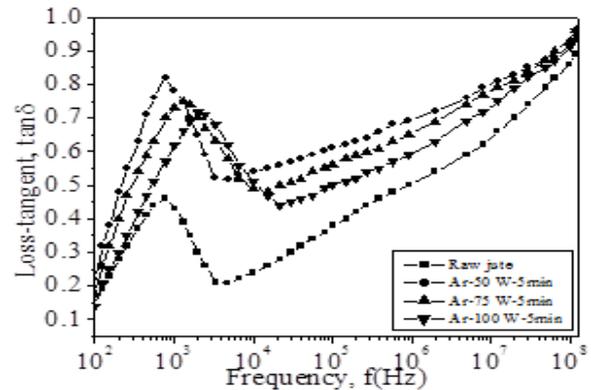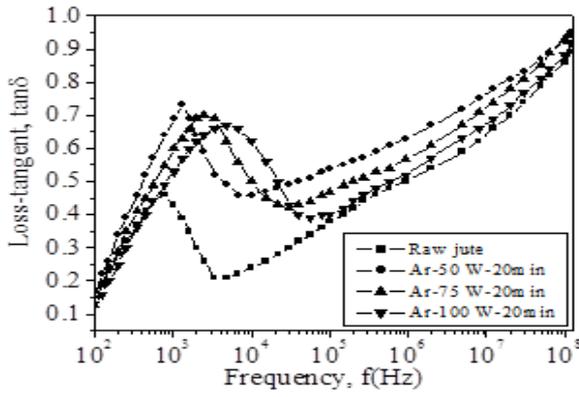
Fig. 4(b): Variation of dielectric loss-tangent with frequency of raw and LTP treated jute at various discharge powers at a constant treatment time for Ar plasma.
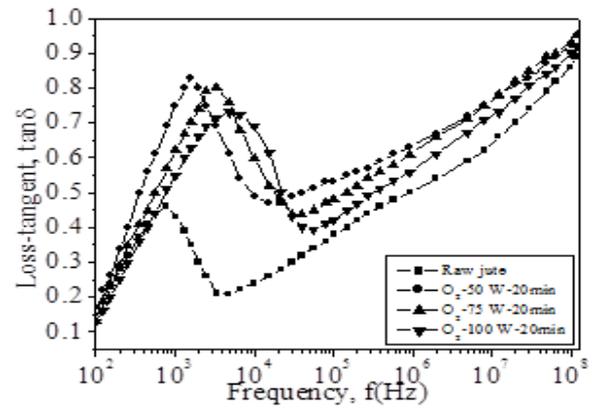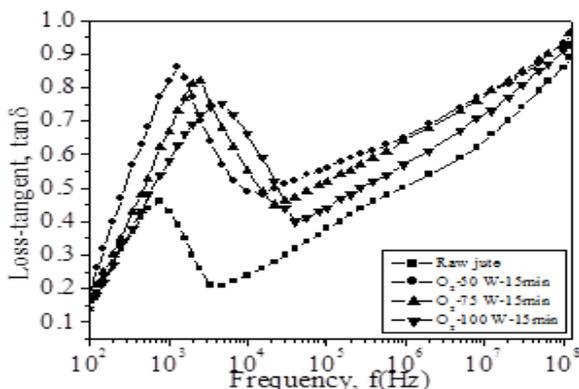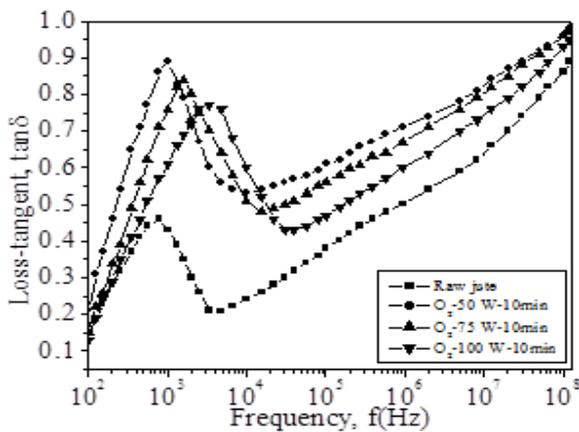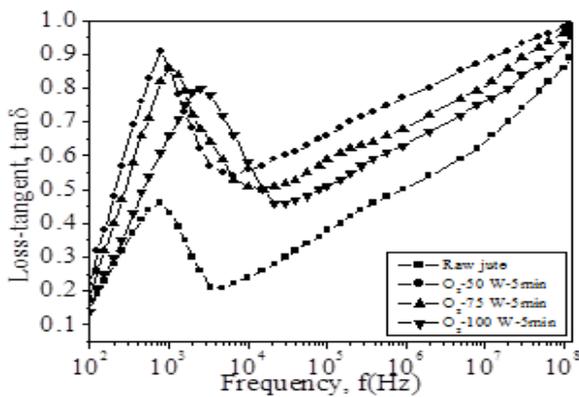


Fig. 4(c): Variation of dielectric loss-tangent with frequency of raw and LTP treated jute at various discharge powers at a constant treatment time for $O_2$ plasma.







## III. DISCUSSION

It is seen from the figures 4 that the values of loss-tangent of raw and LTP treated jute increases as the applied frequency increase and reaches a maximum within the frequency range of $10^3$ to $10^4$ Hz. Above this frequency range the loss-tangent has a decreasing tendency up to the frequency range of $10^5$ Hz and then increases gradually with the increase of frequency. When the hopping frequency is nearly equal to the frequency of externally applied electric field, a relaxation peak is observed. The increase of dielectric loss in low frequency region is dominated by interfacial or ionic polarization.

It is also observed from the figures 4 that the values of loss-tangent decreases as the exposure times as well as the discharge power increase. This is the good agreement with the results found by electrical conductivity analysis in the previous section. In addition, it is seen from the figure 4 that the relaxation peaks are broaden and they are shifted towards the higher frequency side with the increase of exposure time and discharge power. This may be due to the increases of dipole rotation of dielectric material with the increase of exposure times and discharge powers.

## ACKNOWLEDGEMENT

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