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Plasma project (P^2) – An overview

October 8, 2007

In recent years, plasma treatment of textiles has attracted the attention of researchers and industrialists, mainly in the developed world leading to a substantial amount of work towards harnessing the potential held by this technology. Plasma; often referred to as the fourth state of matter has the ability to modify bulk properties of textile substrate by creating chemical and/or physical changes as small as a few nanometers on the surface of fiber assemblies. Furthermore, treatment with plasma has the advantage of being an environmentally friendly process owing to its simplicity of application as a dry application media as well as its potential to cut down on usage of resources which include water, chemicals as well as energy.

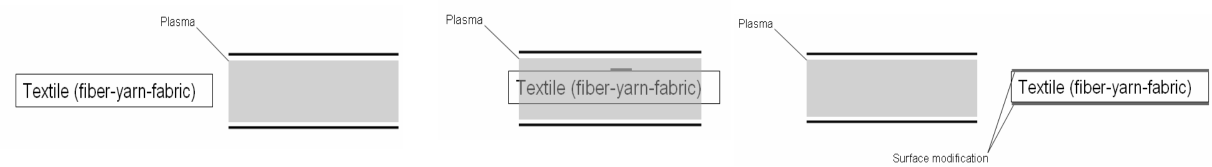


Fig 1 a (left), b (centre) and c (right) showing substrate undergoing surface modification as it passes through plasma.

Equipment for plasma treatment can be divided into two broad categories. Low pressure equipment was developed earlier and more work on plasma treatment of textiles has been documented on the basis of this technology[1]. The more recent development of ‘atmospheric plasma,’ opened up the possibility of continuous treatment using plasma owing to the fact that such systems could operate at atmospheric pressures giving the new technique an edge over its predecessor in terms of functionality as well as offering economic benefits due to the obsolesce of equipment required to reduce and maintain near vacuum pressures.

When a surface is exposed to plasma a mutual interaction between the gas and the substrate takes place. The surface of the substrate is bombarded with ions, electrons, radicals, neutrals and UV radiation from the plasma while volatile components from the surface contaminate the plasma and become a part of it[2]. Whatever may be the final outcome on the surface, the basic effect that causes modification is based on the following phenomena.

A. Radical Formation
    i. Attachment of functional group
    ii. Deposition/polymerization
B. Etching

It is through the use of these in different combinations and on different substrate that the vast variety of outcomes which are possible through plasma treatment can be achieved. For instance, the use of a combination of etching and attachment of functional groups by radical formation to improve the

[1]M. G. McCord et al, Modifying Nylon and Polypropylene Fabrics with Atmospheric Pressure Plasmas, Textile Research Journal, 72(6), 491-498 (2002).
[2]J.G.A. Terlingen, Introduction of functional groups at polymer surfaces by glow discharge techniques, Chapter 2, Europlasma technical paper.

hydrophilic character of cotton fiber surfaces to improve efficiency of desizing[3]. Other studies have been conducted to study dying and scouring behavior of plasma treated cotton[4], shrink resistant treatment of wool by using plasma over environmentally hazardous chlorine based chemicals[5] and to achieve chemical finishes on various fibers by modifying their surfaces using plasma treatment instead of conventional finishes via wet treatment. These are just some of the many application possibilities using plasma treatment, some of which have been suggested by authors to be suitable for industrial application[6].

In an effort to capitalize on the potential held by this technology, a one atmosphere uniform glow discharge plasma panel[7] was constructed to explore the possibility of carrying out experimental work at TRIC. Preliminary tests were conducted using the panel to determine whether plasma was being created and was capable of surface modification. Initial tests lead to some success but results were ambiguous and often unpredictable. It was eventually discovered that the addition of a metal plate to ground the plasma allowed the charged species to travel through the substrate and yield better results. The initial arrangement was thus modified and set up as shown in figure 2 to perform further preliminary tests.

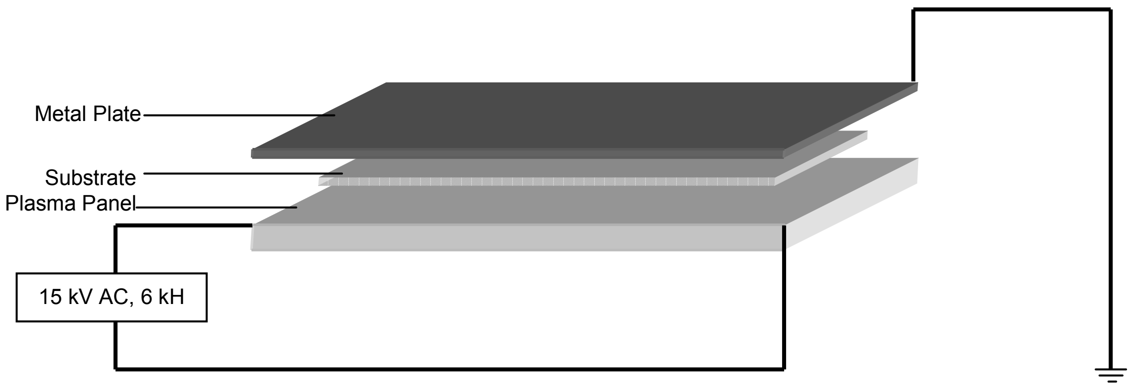
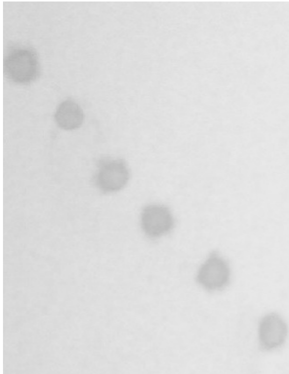


Fig. 2, modified one atmosphere uniform glow discharge panel setup at TIP physics lab for surface modification.

Images 3a and b show the spreading of 0.01% Everdirect Turquiose dye solution on untreated and plasma treated printing paper. While the droplets placed on untreated paper spread evenly and took well over 2 minutes to disperse on the surface, the ones that were placed on the paper which was exposed to the glow discharge device for 5-10 seconds by placing the material between the device and metal plate as shown in figure 2 for the said amount of time, spread much more rapidly assuming a linear path as shown in figure 3b.

[3]Zaisheng Cai and Yiping Qiu et al., Effect of Atmospheric Plasma Treatment on Desizing of PVA on Cotton, Textile Research Journal, 73(8), 670-674 (2003).
[4]D. Sun et al, Effect of low pressure plasma treatment on the scouring and dyeing of natural fabrics, Textile Res. J. 74(9), 751-756 (2004).
[5]Hartwig Hocker, Plasma treatment of textile fibers, Pure Appl. Chem., Vol. 74, No. 3, pp. 423–427, 2002.
[6]Kan Chi-wai et al, The possibility of low-temperature plasma treated wool fabric for industrial use, AUTEX Research Journal, Vol. 4, No-1, (2004).
[7]How to construct a one atmosphere uniform glow discharge plasma panel, http://jnaudin.free.fr/html/s_gdp1.htm



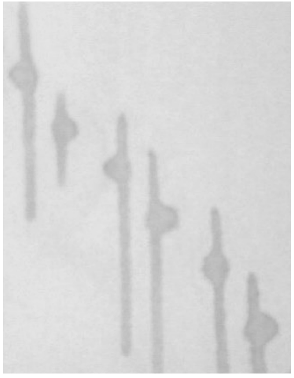
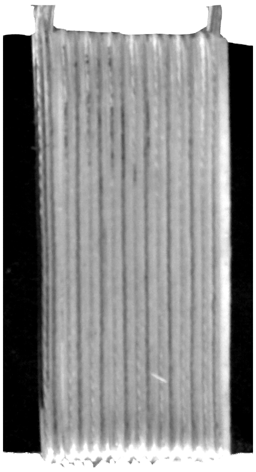


Fig 3a, dye solution droplets on untreated paper

Fig 3b, dye solution droplets on plasma treated paper

The path taken by the droplets can be explained by action of plasma the surface of the substrate in fine vertical lines because of formation of plasma between the wire winding as shown in images 4a and b. Plasma treatment enhances wicking by creating hydrophilic polar groups on the surface of the treated material[8], it can thus be said that water molecules traveled more rapidly along this more hydrophilic path. Analysis through infra red spectroscopy can be used to further confirm the changes in surface chemistry of the material.



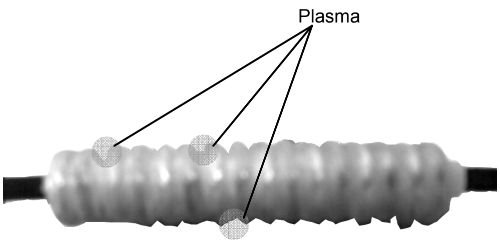


Fig. 4a (left), top view of one atmosphere uniform glow discharge panel and fig. 4b (right), side view of panel showing the inter wire spacing where the plasma is created.

On 100% pure cotton greige fabric, there was a distinct decrease in contact angle when droplets were placed on fabric treated with atmospheric plasma for one minute, which could be observed visually as shown in the image in figure 6 captured by a 1.3 mega pixel camera. The droplets also showed a tendency to be attracted to the region which had been exposed to plasma and rolled over towards such regions.

Fig. 6, change in contact angle on droplets placed on plasma treated (left) and untreated (right) regions on 100% cotton greige fabric.

Treatment of polyethylene terephthalate fabric (fig 5) yielded similar results to those on paper and there seemed to be no apparent change in the behavior of fabric/liquid interaction 24 hours after the treatment.

[8] Roth J. Reece, Industrial Plasma Engineering Volume 2, Institute of Physics Publishing, 2001

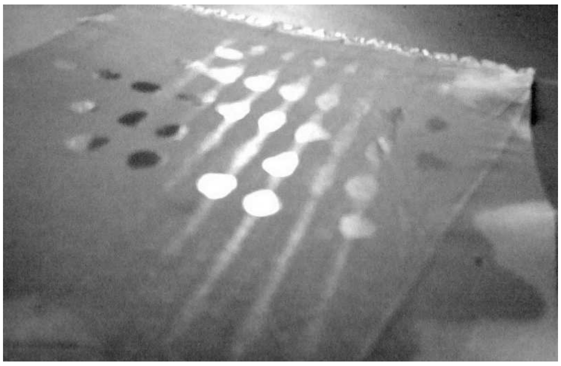


Fig. 5, plasma treated polyester fabric with the treatment area visible because of the preferred path taken by water droplets.

The initial tests conducted so far conclude that plasma is being created by the device and is capable of modifying the surface of fiber assemblies. A scanning electron microscope analysis of treated samples with different exposure times will help ascertain if etching is taking place.

The glow discharge panel can be modified to create more uniform plasma so that all areas of the fabric are treated equally. The treatment can be made more uniform by attaching a rolling mechanism which will carry the fabric between the panel and ground plate over the required amount of time. Also an RF generator can be used to generate a variable potential difference suitable to create plasma and this will enable further manipulation of the plasma according to requirements.

Several research proposals are in development in tandem with work on improving the atmospheric plasma treatment system. Ideas for study are related to modification of dyestuff, particularly disperse dye to determine the impact of plasma treatment on dyestuff solubility and consequently dyeing behavior on polyester. An approach to study the flow behavior of plasma has also been developed; however, the treatment setup needs considerable modification prior to carrying out such tests.

Latest advancements in atmospheric plasma are using liquid precursors to form nano layered coats on textile substrate. If the thickness of these coats can be controlled, it would be interesting to try and achieve diffractive coloration using plasma as attempted, somewhat successfully, through ionic self assembly by Calvert[9]. The equipment required for this is somewhat more complex and is only a recent development. Work at TRIC at this stage will attempt to explore some of the fundamentals of plasma which are still subject to ambiguity and the focus of research groups across the world while trying to develop innovative applications.

Acknowledgements

The development of this circuit would not have been possible for me without the guidance of my friend Mr. Ovais Zuberi, with his knowledge of electronics as a mechatronic engineer.

At TIP, Mr. Farhan Khan provided welcome feedback and suggestions in his frequent visits to the lab during the course of this work and Mr. Noor Ahmed has provided consistent technical support in the physics lab whenever required. The initial setup of this equipment at TIP was made possible with the help of Mr. Adnan Yaseen and credit goes to him for installing the ignition coil in the circuit and connecting the components.

[9] Calvert, Paul D. et al, Nano crafted layered optical filaments for diffractive coloration, NTC project No. M03-MD14, National Textile Centre Report 2005