

# Development and application of in-house high voltage power supply for atmospheric pressure plasma treatment system

Nafarizal Nayan<sup>1,2</sup>, *Member, IEEE*, Mohammad Redzuan Zahariman<sup>2</sup>, Mohd Fadzlie Bin Ahmad<sup>2</sup>, Riyaz Ahmad Mohamed Ali<sup>1,2</sup>, Mohd Zainizan Sahdan<sup>1,2</sup>, Uda Hashim<sup>3</sup> *Member, IEEE*

<sup>1</sup>Microelectronic and Nanoelectronic – Shamsuddin Research Centre (MiNT-SRC),

<sup>2</sup>Department of Electronic Engineering, Faculty of Electrical and Electronics Engineering  
Universiti Tun Hussein Onn Malaysia,

86400 Parit Raja, Batu Pahat, Johor

<sup>3</sup>Institute of Nano Electronic Engineering (INEE)

Universiti Malaysia Perlis,

01000 Seriab, Kangar Perlis

Email: nafarizal@gmail.com, nafa@uthm.edu.my

**Abstract-** Atmospheric pressure plasma is now being widely developed for simple surface treatment process and for fast medical tools sterilization. Plasma surface modification involves the interaction of the plasma generated excited species with a solid interface or coatings. The previous vacuum plasma system is not applicable and very costly. In the present project, we have developed the high voltage power supply and atmospheric pressure plasma using dielectric barrier discharge concept. The high voltage power supply was developed using a simple 555 timer and car's ignition coil. Then, we investigate the plasma surface modification effect from the contact angle measurement and evaluate the roughness using surface profiler. We found that the contact angle decreased with the exposure time and surface roughness changed when exposed with atmospheric pressure plasma. It has been understood that a film coating will be create on glass and silicon surface when expose with atmospheric pressure plasma system in water vapor environment.

## I. INTRODUCTION

Atmospheric pressure plasma has high energy electrons that lead to the generation of chemically active species such as ozone. These highly reactive species are applicable for cleaning of organic dust on material surface, semiconductor substrate surface modification, and medical tools sterilization. In addition, a relatively low temperature in the plasma is suitable for the irradiation on thermal sensitive materials such as plastic tools without damage and stress. Basically, atmospheric pressure plasma is non-equilibrium plasmas produced by the dielectric barrier discharge are very attractive for various industrial applications because of their low-cost, high speed and the ability to operate without vacuum.

Plasma surface modification involves the interaction of the plasma generated excited species with a solid interface. Plasma surface activation means usually plasma treatment when non-polymerizing working gases are used. The chemical surface modification is initiated by the radical reaction of plasma species and the polymer surface. In atmospheric pressure plasma, the surface activation typically takes places with oxygen containing gas mixtures such as ambient air. The advantage of the plasma treatment is the ability to change the surface properties of the most external layers of the material without modifying its bulk characteristics. It means there is no change in mechanical properties too.

In addition, the previous system to clean medical tools need a high vacuum system where is very costly. The high vacuum is normally obtained using the combination of turbo molecular pump backed by rotary pump. The disadvantage by using high vacuum system is not an environment friendly due to the noise produced during pumping. So, development of plasma using atmospheric pressure plasma is very effective. The system is generally consisting of two parallel plate electrode and dielectric plate. A very high voltage is supply to electrode to produce plasma.

In the present work, we have designed and developed our own high voltage pulse generator for atmospheric pressure plasma system. Then, we design and develop the atmospheric pressure plasma system by using dielectric barrier discharge concept. Finally, we investigate the usage of atmospheric pressure plasma system for surface modification application.

## II. HIGH VOLTAGE POWER SUPPLY

Figure 1 shows the block diagram of our pulse high voltage power supply. We use a simple 555 timer circuit and ignition coil to produce a high voltage output. The circuit was firstly designed using Multisim software and their output was simulated, as shown in figure 2 and 3.

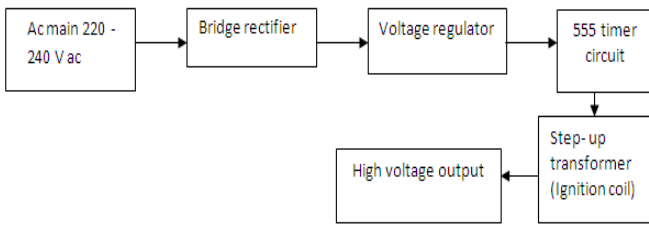


Fig. 1. Block diagram of developed high voltage power supply

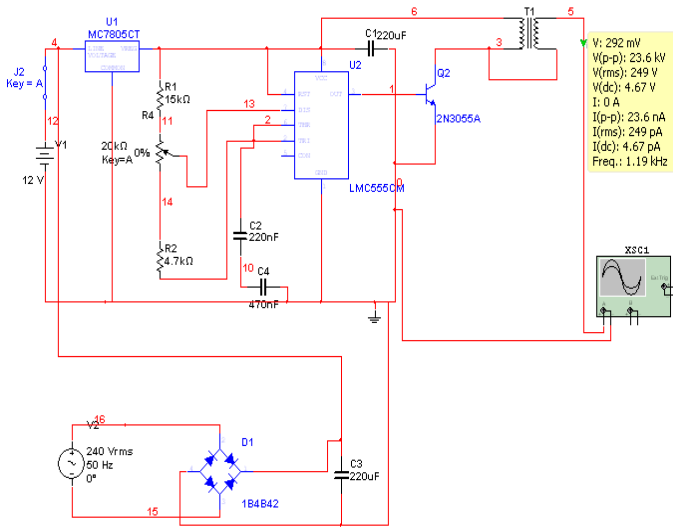


Fig. 2. High voltage circuit in Multisim software

The simulated output from the high voltage circuit diagram is shown in figure 3. It shows that the output sparks from ignition coil appear in the oscilloscope and the range of output voltage in 18-22 kV.

### III. ATMOSPHERIC PRESSURE PLASMA

Figure 4 show the atmospheric pressure plasma using the dielectric barrier discharge concept. The high voltage power supply was connected to the upper metal electrode. The the ground electrode below was covered by quartz glass with 10 mm thickness. The gap between the upper electrode and the quartz glass was created using a microscope glass with thickness of 5 mm.

Prior to the surface treatment process by our in-house dielectric barrier discharge system, we clean the substrate using acetone and ultrasonic cleaner for glass substrate and using acetone, buffer oxide etching and ultrasonic cleaner for silicon wafer. This is to ensure that there is no oxide layer on the top of substrate. One can make sure the hydrophobic of silicon substrate after the cleaning process by dropping water on silicon substrate. Silicon is hydrophobic and silicon dioxide is hydrophilic.

The glass and silicon substrate was then inserted into the gap between the upper electrode and the lower electrode. The plasma was generated using high voltage power supply and exposed to the substrate. The treatment time was varied from 2-17 minutes. Although the plasma color is very dim, one can see small spark coming from the upper electrode to the substrate surface in dark room. Their color is slightly purple.

For the analysis, we used contact angle analysis and surface rougher analysis. The contact angle was evaluated from the image taken from a simple digital camera at specific angle. Then the surface roughness was evaluated using the KL Tencor surface profile system. Even this technique is very simple and rough, we hope that we could give some information of the effect of our plasma exposure to the substrate surface. These results may give us some knowledge on the surface tension activities before and after the plasma treatment.

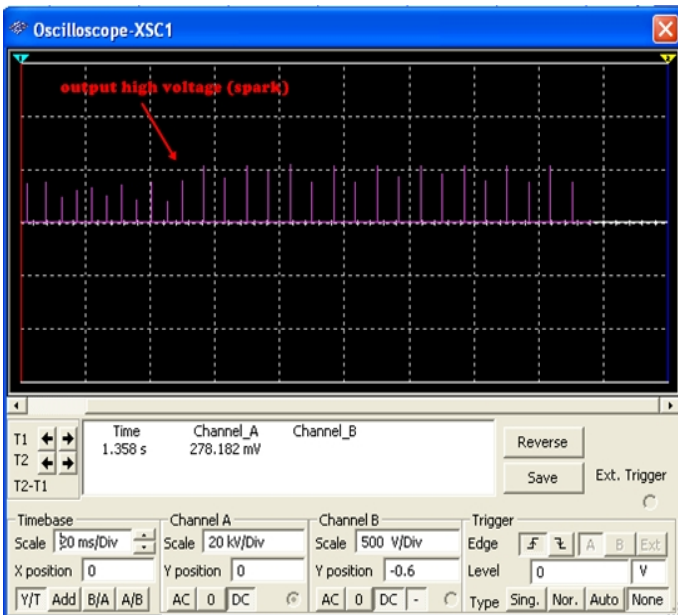


Fig. 3. Output from high voltage circuit simulation

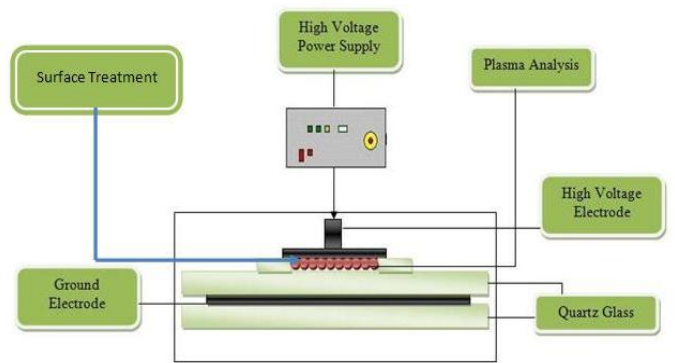


Fig. 4. Dielectric barrier discharge system for surface treatment application

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

For surface treatment process, the exposure time or treatment time was varied from 2 -17 minutes. We expose the substrate at a duty ratio of 66.7% where 2 minute “ON” and 1 minute “OFF”. This is to cool down the circuit and maintain the discharge condition. A water drop from a pipette was observed before and after the treatment on glass and silicon substrate. A water drops behavior on the substrate surface is very instructive. If the water spreads out over the surface this shows the water molecules are more attracted to the surface than to itself. We call this condition as hydrophilic. The attractive quality of a surface is determined by its surface tension. If the water forms a spherical drop, this shows the substrate surface tension is less than that of the water. We call this condition as hydrophobic. As an example the water molecules would rather stick together than attach to the polymer surface molecules.



a) Water drop on an untreated, low energy surface



b) Water drop on the plasma treated surface

Fig. 5. Surface tension effect of plasma before (a) and after (b) plasma treatment on glass substrate

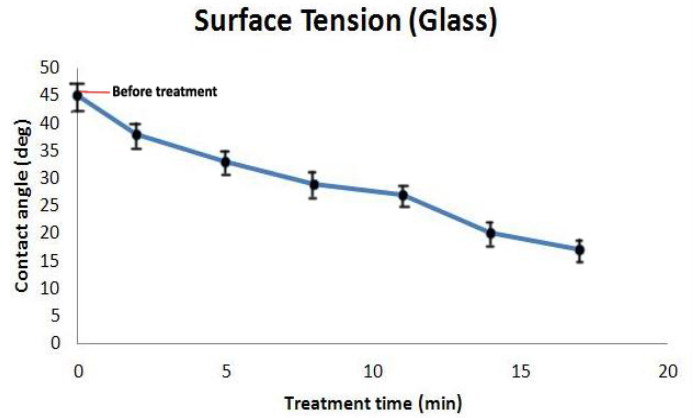


Fig. 6. Effect of DBD plasma exposure time on water contact angle on glass substrate

Figure 6 shows the result of contact angle measurements. Freshly cleaned glass surfaces have a high surface energy and are wettable as shown at 0 min. However, they have a tendency to adsorb organic contamination from the ambient environment. After the treatment procedure, the result show that the contact angle decreased with the treatment time. It has been reported that the adsorbed organic contaminant molecules, generally less than full monolayer coverage of order nm thickness, will generate a heterogeneous wettability. After using atmospheric pressure plasma system for treatment, non uniform glass coatings will be formed. Therefore it will reduce the contact angle by increasing the glass surface wettability.

The use of atmospheric pressure plasma treatment instead of the widely used low pressure vacuum plasma treatment can increase the handling capacity of large area glass substrates, can increase the throughput by in line processing under the atmospheric environment, and can decrease the equipment cost. The surface of glass become hydrophilic after treatment using atmospheric pressure plasma. The higher the tension, the better the thin film will stick provided the surface is not degraded. Then the surface treatment process was repeated on silicon substrate using the similar procedure and parameter.

Figure 7 shows the image of water drop on silicon substrate after the plasma treatment. Before expose plasma on silicon surface, silicon have low energy surface with a contact angle of 40 degree. After 2 min. of exposure time, the surface tension has drastically changed to a very hydrophilic in their surface. Then after 2min., the results were almost the same. That is because we can assume there are some thin layer or coatings has form on silicon surface and this is prove that plasma have make a surface modification surface.



Fig. 7. Surface tension effect of after plasma treatment on silicon

discharge system. The potential reason is due to the existence of monolayer surface on the substrate surface. The results show the potential development of larger scale plasma treatment system for surface modification application. The result of treatment video will be shown during the conference.

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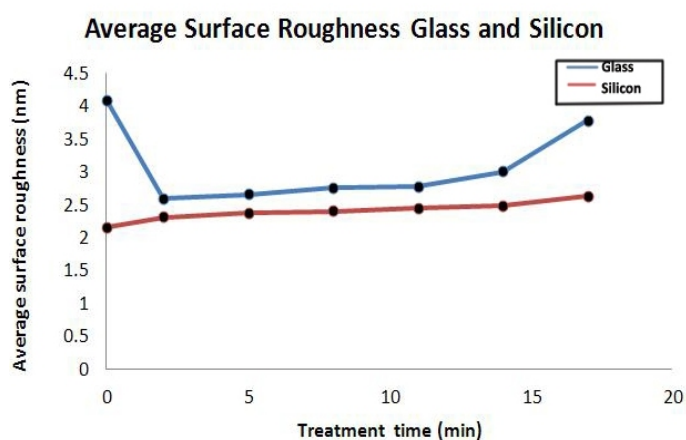


Fig. 8. Average surface roughness on glass and silicon surface evaluated by surface profiler meter

The wettability of silicon substrate surface is may be due to the increase in the hydroxyl  $-OH$  groups density, which are responsible for the hydrophilic properties. This is significant due to the presence of water vapor in the working environment.

Finally, the surface roughness was evaluated using surface profiler. The results are shown in figure 8. As shown in the figure 8, the surface roughness for silicon substrate was almost the same. On the other hand, the surface roughness for glass substrate decreased with the treatment time. This is consistent with the contact angle result.

#### IV. CONCLUSIONS

We have successfully developed the high voltage power supply and applied it to produce atmospheric pressure plasma system. The atmospheric pressure plasma system was used for the surface treatment on glass and silicon substrate. We have shown that the surface modification occurred when we expose the substrate surface with our in-house dielectric barrier