Hydrophobic treatment of various substrates by atmospheric pressure plasma

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Abstract

Hydrophobic treatments were conducted for different kinds of substrates, glass substrate, silicon wafer and plastic substrate. Ar-CH_4 gas mixture was used as a discharge gas for the hydrophobic treatment. The change of the contact angle before and after treatment was measured and compared. Time evolution of the contact angle change after hydrophobic treatment was investigated.

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1. Objectives and Background

Many processes in daily life, biology and industry depend on the surface energy of solids. Therefore, assessment of this surface energy is important for a variety of reasons.[1] The surface preparation on a large scale divides with dry process and wet process, in which the plasma is the dry surface preparation method which is representative. In recent years, non-thermal plasmas under atmospheric pressure have attracted considerable interest for surface modification of materials.[2] This environment friendly dry treatment can modify the surface properties of materials without changing the chemical and physical properties of the bulk.[3] Furthermore, the operation of such a process at atmospheric pressure requires no vacuum equipment, and so the processing cost is reduced and the feasibility of continuous processing is improved, and therefore large-scale industrial applications are possible.[4] Among various atmospheric pressure non-thermal plasmas, the DBDs (dielectric barrier discharges) are studied mostly for the easy formation of stable plasmas and their scalability, and numerous studies concerning surface modification of material using DBDs under atmospheric pressure have been undertaken.[5] In some industrial applications, for example, in display production process, semiconductor process, ink-jet printing, the surface of glass or ceramic insulators needs good hydrophobic properties to prevent the occurrence of contamination flashover. In order to improve the hydrophobicity of the insulator surface, silicone oil and silicone grease are widely used; their excellent hydrophobic properties help make a protective coating on the insulator surface.[6] However, this coating on the insulator surface does not react chemically with the insulator surface molecules, and thus it cannot form a stable hydrophobic layer. Non-thermal plasmas under atmospheric pressure offer a new approach to hydrophobic of surfaces. In this study we are to investigate on the hydrophobic treatments of the various kinds of the substrates (glass, Si wafer, plastics etc.) to find out the possible application of atmospheric pressure plasma treatment for various industries such as flexible display, semiconductor, PCB and solar cell.

2. Experimental

For the experiments, two types of the plasma heads were prepared as is shown in Fig. 1. (a) is a direct type head, in which all of the species generated from the gas discharge such as positive ions, electrons, neutral atoms, radicals give a direct influence on the substrates. (b) is a remote type, in which gas discharge is generated inside the plasma head, therefore neutral atoms and radicals are main species which give an influence on the substrates. These two are different for the mechanism of the surface treatment and the effectiveness of the processes. Therefore, in this study, we did a hydrophobic treatment on the substrates using these heads and compared the results.

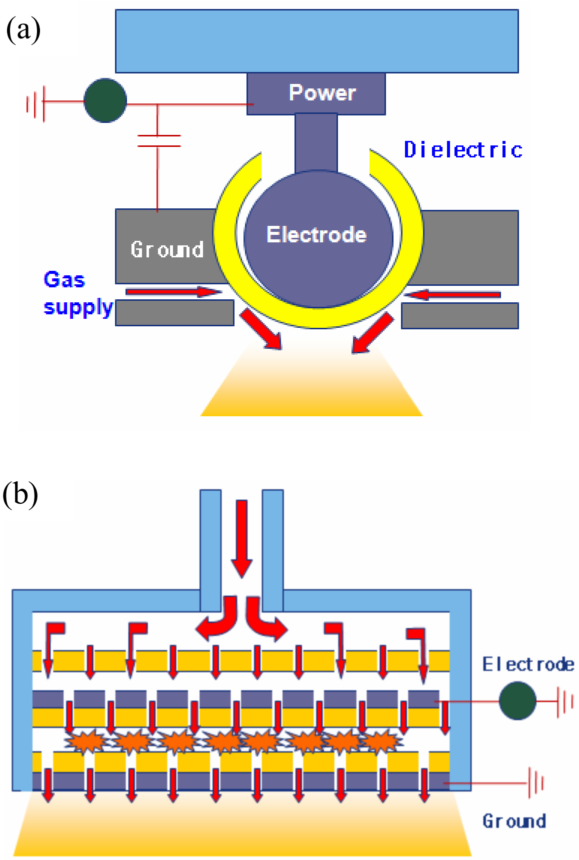


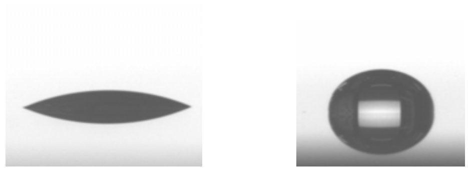
Fig. 1. Two types of the plasma head which was used for this study.

(a) Direct type (b) Remote type

Hydrophobic treatments were conducted for different kinds of substrates, glass substrate, silicon wafer and plastic substrate. Ar-CH_4 gas mixture was used as a discharge gas for the hydrophobic treatment. The best gas mixture to get the stable discharge was Ar/CH_4(2 L/min) and He_2(10 L/min). The distance between the plasma head and the substrates was determined within the range of 2~5mm to get the most stable discharge. Moving speed of the substrates was fixed as 20mm per minute. Plasma treatment was repeated several times to investigate the change of the contact angle with the variation of the treated time. The discharge power was fixed as 180 Watt to consider stable discharge condition.

The change of the contact angle before and after treatment was measured to examine the hydrophobic treatment effect. Time evolution of the contact angle change after hydrophobic treatment was investigated also.

3. Results



(a) before (b) after

Fig. 2. Microscopic observations which show the change of contact angle due to the hydrophobic treatment.

Fig.2. shows the comparison of the contact angle of before and after plasma treatment. It is well known that in the droplet test there is a following relationship in equilibrium state in Fig.3.

$$\gamma_S = \gamma_L \cos\theta + \gamma_{SL} \qquad \text{eq.1}$$

wherein, γ_S is a surface free energy of the substrate, γ_L is a surface tension of the liquid droplet, θ is a contact angle and γ_{SL} is a interface energy between the liquid and the substrate. High contact angle means lower surface free energy, in which surface of the substrate itself is stable so the liquid droplet is difficult to enlarge its contacting area. This hydrophobic characteristic is useful in the case which needs a fine pattern on the substrate or a non-wetting surface.

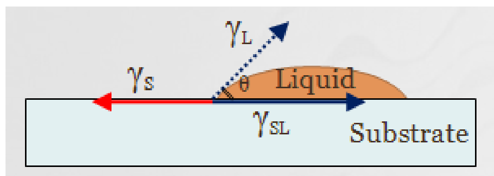


Fig. 3. Schematic drawing which explains the equilibrium state when a droplet is wetting on the substrate.

Fig.4. shows the change of the contact angle after hydrophobic treatment using the direct type plasma head. As is shown in the figure, for all substrates used in this study, high contact angle around 90 degree was obtained after 10 repetitive plasma treatments. More repetitive works didn't make a meaningful change of the contact angle any more. However, in case of PMMA, the substrate was physically damaged by the plasma and couldn't be measured after 20 times repeat.

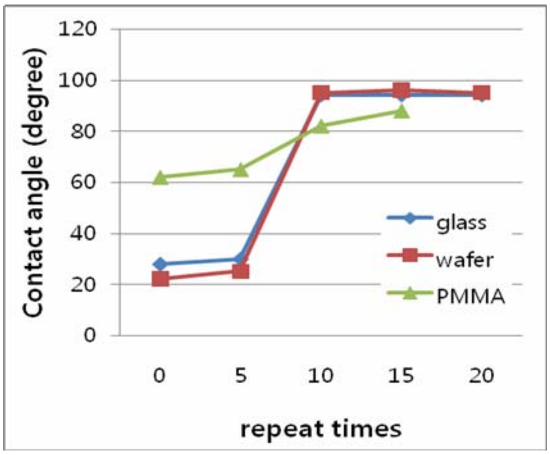


Fig. 4. The changes of the contact angle after hydrophobic treatment using direct type plasma head.

Fig.5. shows the change of the contact angle after hydrophobic treatment using the remote type plasma head. In the figure, very similar characteristics of the change in the contact angle were observed compared to the case of the direct type in Fig.4. High contact angle around 90 degree was obtained for the three different substrates. However, in this case, PMMA substrate was not physically damaged by the plasma after 20 times repeat. This is explained that in remote type plasma the plasma species are distributed inside the plasma head and only the neutral atoms and radicals are transmitted on the surface of the substrate, in which the physical damage on the substrate is smaller than direct type plasma. More works is needed to investigate the differences of the effects which the plasma species give during the hydrophobic treatment,

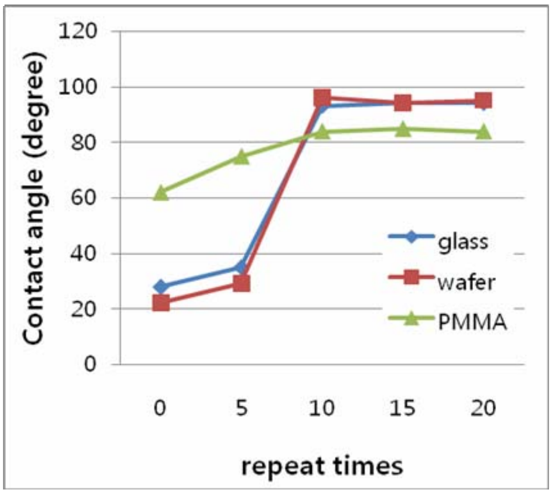


Fig. 5. The changes of the contact angle after hydrophobic treatment using remote type plasma head.

Fig.6. shows the change of the contact angle for the same position on the substrate with the time evolution exposed to the open air after 10 repetitive treatments. As is shown in the figure, the contact angle was decreased with the exposed time for all the substrate. Judging from the change of the contact angle, it is said that the hydrophobic characteristic is maintained until about 1 hour, and fades away gradually after that time.

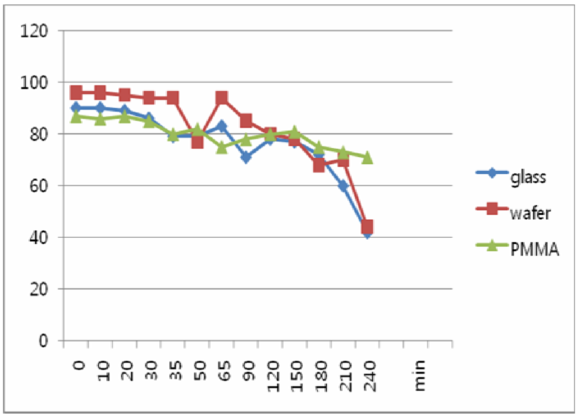


Fig. 6. Time evolutions of the contact angle on the substrates when exposed to open air after 10 repetitive plasma treatments.

4. Summary

The hydrophobic treatments were conducted using direct type plasma head and remote plasma head with the gas mixture of Ar/CH_4(2 L/min) and He_2(10 L/min). Judging from the high contact angle around 90 degree on the substrate, it can be said that all of the three different substrates, glass, Si wafer and PMMA, exhibit the hydrophobic characteristics. These hydrophobic characteristics were obtained from both of the plasma heads. The hydrophobic characteristics were maintained until about 1 hour when exposed to open air.

5. Acknowledgements

This work was supported by Ministry of Knowledge Economy in Korea.

6. References

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