IMPROVEMENT OF GLASS WETTABILITY USING DIFFUSE COPLANAR SURFACE BARRIER DISCHARGE AND GLIDING ARC CONSIDERING AGING EFFECT

Vlasta Štěpánová[1*], Pavel Slavíček[1], Miroslav Valtr[2,3], Vilma Buršíková[1], Monika Stupavská[1]

[1]Department of Physical Electronics, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic
[2]Czech Metrology Institute (CMI), Okružní 31, 638 00 Brno, Czech Republic
[3]CEITEC BUT, Technická 10, 616 00 Brno, Czech Republic

Abstract

Increase of surface wettability on glass was observed after atmospheric pressure plasma treatment using two different plasma sources. First used plasma source was Diffuse coplanar surface barrier discharge (DCSBD) and second was commercial gliding arc. Standard microscopic cover glasses were used as a substrate. Examined parameters were water contact angle, aging effect of plasma treatment, and surface roughness. Different exposure times (10 s, 20 s) of plasma treatment were examined. The influence of plasma treatment on surface roughness was investigated. Aging effect of plasma treatment was faster on glass treated with gliding arc, than on glass treated with DCSBD. Therefore DCSBD is a more suitable device for plasma treatment of glass than gliding arc.

Keywords: plasma treatment, glass, surface wettability, DCSBD, gliding arc

1. INTRODUCTION

Glass is commonly used in building, automotive, and consumer industry. Processing of glass consists of many operations, for example gluing, printing, coating, etc. Good adhesion of glass surface is important for these operations. Surface properties of glass play a critical role in applications, for example the increase of surface roughness is an undesirable effect.

Plasma treatment can change surface properties, enhances wettability [1], improves adhesion and cleanness [2] of glass substrate. Dielectric barrier discharge (DBD) plasma treatment can be used as pre-treatment of glass for preparation of hydrophobic films [3]. Plasma cleaning of polymeric fibres before coating is described in literature [4]. Applications of biomolecule attachment on plasma modified glass are known [5].

The aim of this study is to compare the plasma treatment of soda-lime glass with DCSBD and with gliding arc. Soda-lime glass was chosen for its homogeneity and small initial roughness. Both plasma discharges, DCSBD and gliding arc, operate at atmospheric pressure and air is used as a carrier gas. The benefit of DCSBD is a large discharge area and plasma homogeneity. Gliding arc has a higher temperature of produced plasma. The parameters which were observed were contact angle, aging effect of plasma treatment, and surface roughness.

2. EXPERIMENTAL

2.1 Material

Standard cover glasses (Corning, Sigma-Aldrich) were used for experiments. It was soda-lime glass with dimensions 22 × 44 mm and thickness 0.16-0.19 mm.

2.2 Plasma sources

Special type of dielectric barrier discharge so-called Diffuse coplanar surface barrier discharge (DCSBD) [6] at atmospheric pressure has been used for plasma treatment. The DCSBD was developed by the working group of Prof. Černák at the Department of Physical Electronics. This type of discharge has already found application in treatment of metals [7-9], rabbit fibres [10], glass [11], low-added-value materials [12], etc. The DCSBD operates at the frequency of 15–50 kHz in ambient air with discharge power in the range 100-600 W. Power of 400 W and frequency of 15 kHz were used in present work. The discharge area is 8 × 20 cm and effective area of plasma, produced by the DCSBD, is 160 cm^2. Thickness of plasma generated from this discharge is about 0.3 mm.

Gliding arc Plasma APC 500 (Diener Electronics, Germany) was a second type of plasma source used for surface modification. It is a commercial plasma source. This plasma source [13] operates at generator frequency 40 kHz and discharge power is approx. 500 W. The high voltage generator produces voltage up to 10 kV. Corona head is formed by two electrodes. The air flow stretches the arc out of the electrode area. Treatment width is approx. 50 – 60 mm. This device is to be used on non conductive surfaces. The gliding arc is not stable in time. The plasma filaments are still moving, because of air flow inside of the discharge, and therefore the produced plasma is not so homogeneous as DBD.

Fig. 1 DCSBD discharge unit producing homogeneous plasma.

Fig. 2 Commercial gliding arc – Plasma APC 500.

2.3 Instrumentation

Surface Evaluation Energy System (See System) was used for drop shape analysis. See System device was developed in Advex Instruments [14], which is a spin-off company of Masaryk University. This device is a portable computer-based instrument for contact angle measurement and surface energy determination. The software enables the calculation of the surface energy on the basis of the most often used models. Deionized water was used for contact angle measurements and used drop volume was 1 µl. Ten measurements of contact angles were done for each sample.

Atomic force microscopy (AFM) images were measured by Accurex IIL TopoMetrix (Bruker) device with probe head operated in contact regime. Tip MSCT-EXMT-A1 (Veeco) with the toughness k = 0.05 N m^{-1} was used. Scanning velocity of the tip was 20 µm/s and resolution of resultant images achieved 500 × 500 px. Dimensions of analysed area were 10 × 10 µm. The surface topography was measured under room temperature and ambient atmosphere. Parameters R_a and R_{RMS} were used to quantify the surface roughness. AFM images were analyzed using the Gwyddion software [15].

3. RESULTS AND DISCUSSION

3.1 Wettability measurements

Plasma treatment of glass resulted in the significant increase of the surface wettability. Contact angle decreased from the original value of 43° (Fig. 3) to almost zero value, immediately after plasma treatment. Plasma modified glass was totally hydrophilic, that sessile drop was immediately flat. Therefore value < 10° for contact angle is written in Table 1 for samples measured (a) immediately after treatment and (b) 1 day after treatment. Contact angles were measured directly after plasma treatment and than 1 day, 4 days, 7 days, 11 days, and 14 days after plasma treatment. Glass samples were aged in ambient air. All values of contact angles are listed in Table 1.

Table 1 Comparison of aging effect for plasma treatment with a) DCSBD, b) gliding arc.

	0 day	1 day	4 days	7 days	11 days	14 days
DCSBD 10 s	< 10°	< 10°	10.5±1.7°	25.9±2°	21.0±0.9°	22.1±1.2°
DCSBD 20 s	< 10°	< 10°	12.5±3.6°	24.4±1.2°	23.1±1.1°	24.8±1.5°
ARC 10 s	< 10°	< 10°	31.0±2.3°	33.4±1.5°	39.1±1.8°	39.3±1.8°
ARC 20 s	< 10°	< 10°	31.7±1.7°	34.4±2.6°	38.7±3.3°	40.0±1.8°

Fig. 3. Water contact angle of untreated glass sample.

The contact angle 4 days after plasma treatment is 3 times bigger for plasma treatment with gliding arc (31.5°) than for plasma treatment with DCSBD (10.5°), as can be seen in Fig. 4.

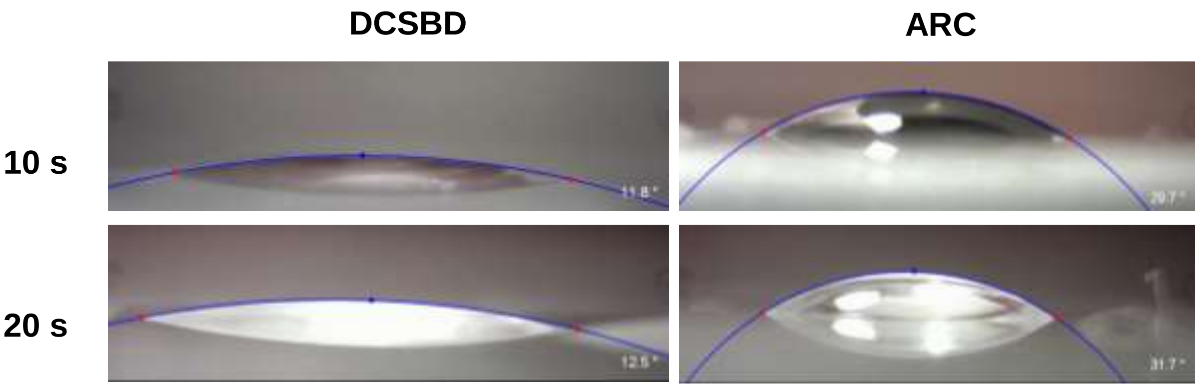

Fig 4. Water contact angles of plasma treated glass samples - 4 days after treatment – depending on the type of discharge (DCSBD, gliding arc) and treatment time (10 s, 20 s).

Contact angles 14 days after plasma treatment are presented in Fig. 5. After 14 days, the contact angle of DCSBD plasma treated glass (22.1°) increased to the half value for the original contact angle of untreated glass. While contact angle of glass treated with gliding arc is close to the original value of untreated glass, after 14 days.

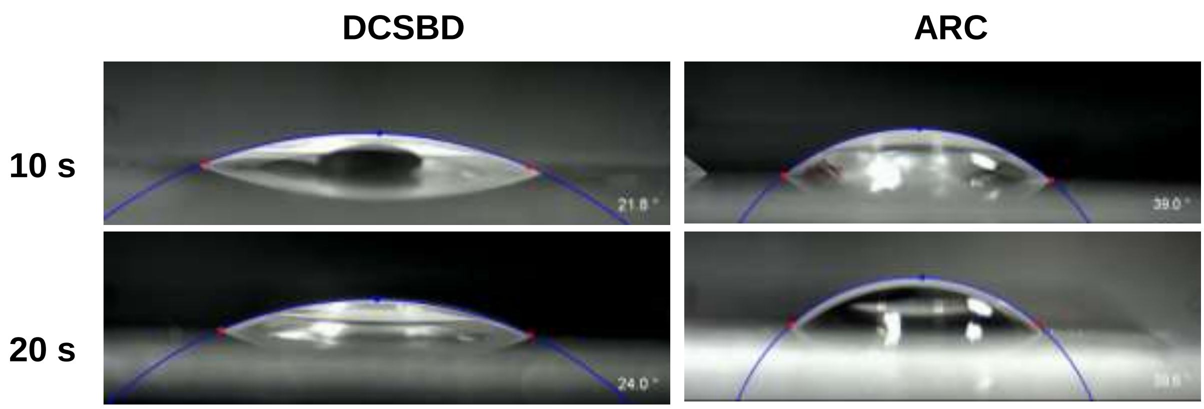

Fig 5. Water contact angles of plasma treated glass samples - 14 days after treatment – depending on the type of discharge (DCSBD, gliding arc) and treatment time (10 s, 20 s).

Effect of longer plasma treatment time (20 s) was negligible. Aging effect of 20 s plasma treated glass was almost the same as aging effect of 10 s plasma treated glass.

Increase of wettability after plasma treatment was proved for both discharges. However the wettability change was more stable in time for DCSBD plasma treatment.

3.2 AFM measurements

Values of R_{RMS} for plasma treated glass were in range 1.8 - 5.7 nm, while value of R_{RMS} for untreated glass reached 1.9 nm. R_{RMS} roughness is slightly higher for plasma treated glass with gliding arc (4.1 - 5.7 nm), than for glass treated with DCSBD (1.8 - 3.1 nm). Calculated parameters R_a and R_{RMS} are listed in Table 2.

Table 2. Values of surface roughness for plasma modified and untreated glass.

	Ra [nm]	*R_{RMS}* [nm]
untreated	**1.2**	**1.9**
DCSBD 10 s	**1.4**	**1.8**
DCSBD 20 s	**2.2**	**3.1**
ARC 10 s	**2.4**	**4.1**
ARC 20 s	**3.7**	**5.7**

Cross-sections of glass surface treated with different discharges are presented in Fig. 6. Roughening effect of glass treated with DCSBD (10 s, 20 s) is almost negligible. A small increase of surface roughness on glass treated with gliding arc (10 s, 20 s) was observed. We can conclude that surface roughness was only slightly affected with plasma treatment.

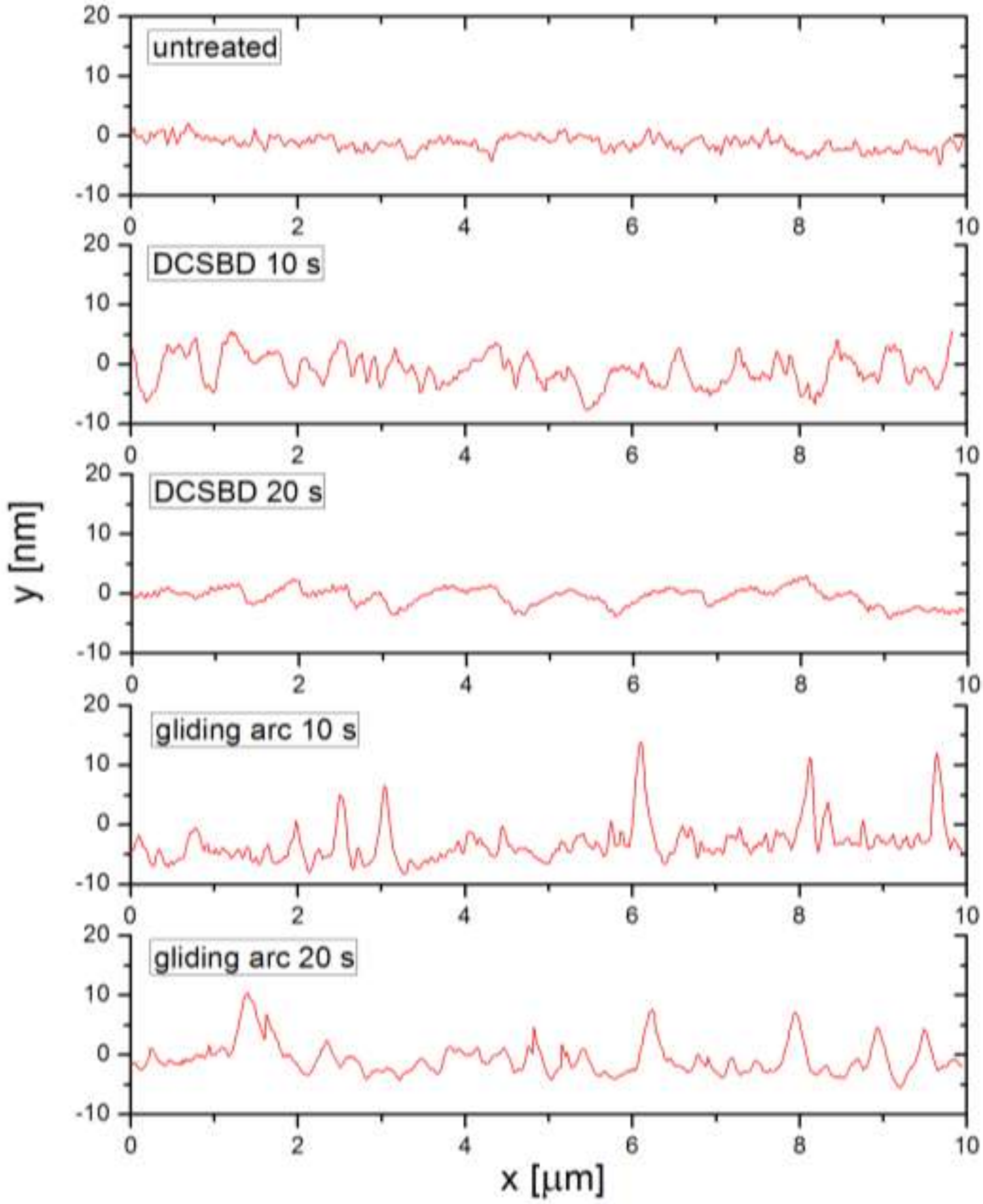

Fig 6. Cross-sections of glass surface treated with different type of discharges (DCSBD, gliding arc) for various treatment times (10 s, 20 s).

4. CONCLUSION

The plasma treatment of glass using two different types of discharges was studied. Contact angle measurements proved increase of wettability after plasma treatment with both discharges. Plasma treated glass was totally hydrophilic after plasma treatment. Contact angle decreased from the original value of 43° to unmeasurable value, glass surface was so hydrophilic immediately after plasma treatment. Shorter time of plasma treatment (10 s) was sufficient for wettability change. Aging effect of plasma treatment was investigated using the contact angle measurements. One day after treatment no wettability change was observed. The contact angle after 4 days was 3 times bigger for plasma treatment with gliding arc than for plasma treatment with DCSBD. After 14 days, the contact angle of DCSBD plasma treated glass increased to the half value for the original contact angle of untreated glass. While contact angle of glass treated with gliding arc was after 14 days close to the original value of untreated glass. Aging effect of plasma treatment was more obvious on glass treated with gliding arc, than with DCSBD. The influence of plasma treatment on surface roughness was investigated. Surface roughness of glass was only slightly affected with plasma treatment. A small increase of roughness was obvious on glass treated with gliding arc. Effect of glass hydrophilization was proved for both discharges. However, the wettability change was more stable in time for DCSBD plasma treatment. The results indicate that DCSBD plasma is more efficient for the improvement of hydrophilicity than gliding arc.

ACKNOWLEDGEMENTS

This research has been supported by the project CZ.1.05/2.1.00/03.0086 funded by European Regional Development Fund, by project LO1411 (NPU I) funded by Ministry of Education Youth and Sports of Czech Republic, and by EMRP research programme "Six degrees of freedom" jointly funded by the EMRP participating countries within Euramet and the European Union.

REFERENCES

[1] LIM K.-B., LEE D.-CH. Surface modification of glass and glass fibres by plasma surface treatment. Surface and Interface Analysis. Vol. 36, 2004, pp. 254-258.

[2] HOMOLA T., MATOUŠEK J., MEDVECKÁ V., ZAHORANOVÁ A., KORMUNDA M., KOVÁČIK D., ČERNÁK M. Atmospheric pressure diffuse plasma in ambient air for ITO surface cleaning. Applied Surface Science, Vol. 258, 2012, pp. 7135-7139.

[3] WANG CH., HE X. Preparation of hydrophobic coating on glass surface by dielectric barrier discharge using a 16 kHz power supply. Applied Surface Science, Vol. 252, No. 23, 2006, pp. 8348-8351.

[4] KELLER M., RITTER A., REIMANN P., THOMMEN V., FISCHER A., HEGEMANN D. omparative study of plasma-induced and wet-chemical cleaning of synthetic fibers. Surface and Coatings Technology, Vol. 200, 2005, pp. 1045-1050.

[5] LARSON B. J., HELGREN J. M., MANOLACHE S. O., LAU A. Y., LAGALLY M. G., DENES F. S. Cold-plasma modification of oxide surfaces for covalent biomolecule attachment. Biosensors and Bioelectronics. Vol. 21, 2005, pp. 796-801.

[6] ŠIMOR M., RAHEL J., VOJTEK P., ČERNÁK M., BRABLEC A. Atmospheric pressure diffuse coplanar surface discharge for surface treatments. Applied Physics Letters, Vol. 81, No. 15, 2002, pp. 2716-2718.

[7] PRYSIAZHNYI V., VAŠINA P., PANYALA N.R., HAVEL J., ČERNÁK M. Air DCSBD plasma treatment of Al surface at atmospheric pressure. Surface and Coatings Technology, Vol. 206, 2012, pp. 3011-3016.

[8] PRYSIAZHNYI V., SLAVÍČEK P., ČERNÁK M. Aging of plasma-activated copper and gold surfaces and its hydrophilic recovery after water immersion. Thin Solid Films, Vol. 550, 2014, pp. 373-380.

[9] BÓNOVÁ L., ZAHORANOVÁ A., KOVÁČIK D., ZAHORAN M., MIČUŠÍK M., ČERNÁK M. Atmospheric pressure plasma treatment of flat aluminum surface. Applied Surface Science, Vol. 331, 2015, pp. 79-86.

[10] ŠTĚPÁNOVÁ V., SLAVÍČEK P., STUPAVSKÁ M., JURMANOVÁ J., ČERNÁK M. Surface chemical changes of atmospheric pressure plasma treated rabbit fibres important for felting process. Applied Surface Science, Vol. 355, 2015, pp. 1037-1043.

[11] ŠTĚPÁNOVÁ V., SKÁCELOVÁ D., SLAVÍČEK P., ČERNÁK M. Diffuse coplanar surface barrier discharge for cleaning and activation of glass substrate. Chemické listy, Vol. 106 S, 2012, pp. 1495-1498.

[12] ČERNÁK M., ČERNÁKOVÁ L'., HUDEC I., KOVÁČIK D., ZAHORANOVÁ A. The European Physical Journal Applied Physics, Vol. 47, 2009, pp. 1-6.

[13] http://plasma.de/en/plasmasystems/plasma-apc500.html accessed on 28.9.2015

[14] http://www.advex-instruments.cz/ accessed on 28.9.2015

[15] NEČAS D., KLAPETEK P. Gwyddion: an open-source software for SPM data analysis. Central European Journal of Physics, Vol. 10, No. 1, 2012, pp. 181-188.