

Characterization of Flow Disturbances Excited by SDBD Plasma Actuator

Alexander M Frolov, Sergey B Leonov, Ivan A Moralev, Victor R Soloviev
Joint Institute for High Temperature RAS, Moscow, 125412, Russia, leonov@ihed.ras.ru
Dmitry Opaitis, Richard Miles, Princeton University, 08540, NJ, USA

This paper considers some unique features of the surface dielectric barrier discharge (DBD) based on time resolved measurements of geometry of plasma area and velocity of plasma-induced flow. These experimental results have significant impact in the design and understanding of DBD operation in applications for flow control. The objective of this work is to perform the time resolved details of SDBD evolution in order to make clearer the physical mechanism of plasma-flow interaction and, finally, to maximize the local and instant amplitude of the plasma effect.

The complex structure of the DBD discharges should obviously lead to onset of the 3D disturbances in the BL. Varying the parameters of the discharge (voltage and freq), one can vary the distance between streamers, therefore changing heat/force sources distribution, adapting it to the spatial wavelength required. Spatial structure of the surface DBD discharges, especially at high carrying frequencies, appears to be non-homogeneous. Due to the discharge volume instabilities, discharge constricts to a number of filaments with higher current densities. Micro-discharges spacing and behavior are ruled by two main processes: charge deposition on the dielectric surface and heating of the gas in the discharge channels.

Past 10-15 years, many studies have been conducted on boundary layer (BL) actuation by surface dielectric barrier discharge (SDBD) [1-4]. These discharges directly act on gas momentum by the mechanism of charge separation and momentum transfer in collisions of electrons and ions with neutral gas molecules [5-7]. In most cases the average magnitude of the plasma-induced velocity is rather small and ineffective for high-speed flow control. Another mechanism for BL separation control by SDBD is the improvement of flow stability by the addition of disturbances to the BL at a particular frequency. In this regard the magnitude and time characteristic of the local plasma-induced thermal or non-thermal fluctuations may be more important than the amplitude or direction of discharge-induced gas movement [6-7].

The experimental approach includes time resolved pressure measurements of plasma-induced flow in air and in nitrogen, fast cam imaging, and PMA-based measurements of the parameters of the DBD luminosity. In the case of air the concentration of negative ions produced due to electron attachment to molecules is expected to be high enough to contribute into the body force; in the case of pure nitrogen no negative ions are created and the negative volumetric charge is presented by electrons.

The experiments were made in a conventional non-symmetrical electrode configuration of SDBD at voltage amplitude $U \leq 12\text{kV}$ and a sinusoidal/rectangular waveform with a variable frequency $f = 0.02\text{-}5\text{kHz}$ [6]. The dielectric plate was made of MACOR™ with a thickness $d = 1\text{mm}$. In some tests a small (0.5-3mm in X direction) triangle tip was attached to the exposed electrode. To explore the behavior of the discharge luminosity area optical measurements of its length have been carried out simultaneously with the recording of the electrical parameters.

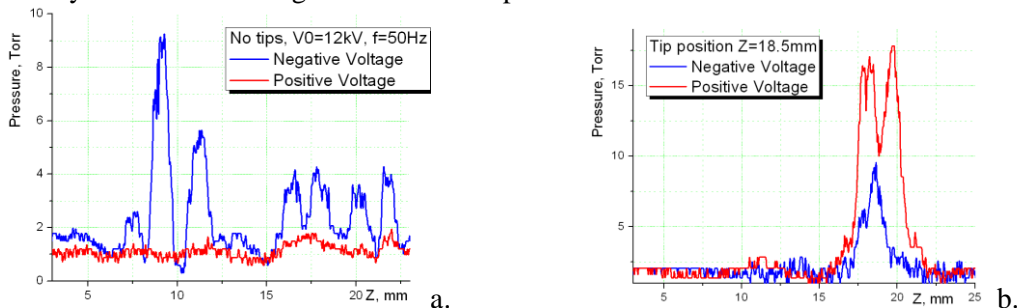


Fig.1. Amplitude of the pressure signal along the exposed electrode. Plain (a) vs tipped electrode (b).

Spatial distribution of the discharge-related momentum. Large variations in the pressure signal along Z direction were observed. The plasma-induced flow field appears to be made up of a few individual jets, where the pressure signal amplitude is higher by a factor of 10 or more compared to other locations along the electrode. The typical gas velocity in these jets is $V_{ind} = 1\text{-}5\text{m/s}$, which

corresponds to a measured pressure of about $P=0.7-17\text{Pa}$. No correlation of the DBD-jet position with streamers was found. The maximum effect was achieved with a small triangle tip attached to the exposed electrode. The spatial distribution of the maximum signal at positive and negative polarities of the voltage applied is rather complex as shown in Fig.1 for a plain electrode (a) and for a tipped electrode (b). A notable peculiarity of the signal at the plain electrode is the non-zero baseline for both polarities, although this value is close to limit of the sensor's signal/noise ratio. Only powerful streamers' corona (which is certainly observed by high-speed camera) originating in higher electric fields near an electrode tip could produce a body force comparable with a force, generated at negative polarity of electrode.

Nitrogen vs Air. These comparisons are the most impressive: there was no pressure signal under negative slope of the voltage at all on either the tipped or the plain exposed electrode in pure nitrogen.

Maximum pressure signal. Under the conditions of this experiment the maximum amplitude of the pressure signal was measured in air for the electrode with a tip. The value of this pressure corresponds to induced flow velocity $V_{max}=12.5\text{m/s}$. No notable variation of the time-averaged local plasma-induced pressure has been detected on the tipped electrode with supplying voltage frequency variation in the range of 20-2000Hz.

Rectangle vs Sinusoidal. The application of a rectangular voltage waveform to the DBD results in a pressure signal with a sharper leading edge. It allows the identification of two types of features in the pressure trace: those induced by the thermal driving force and those induced by ionic wind. As indicated in Fig.2, a thermal push impacts the sensor the first. The second wave, arriving after the thermal wave, is the ionic wind and has a velocity of several m/s. It seems that the "negative" DBD-jet is narrower, than the "positive" one, because it keeps the momentum for a longer distance.

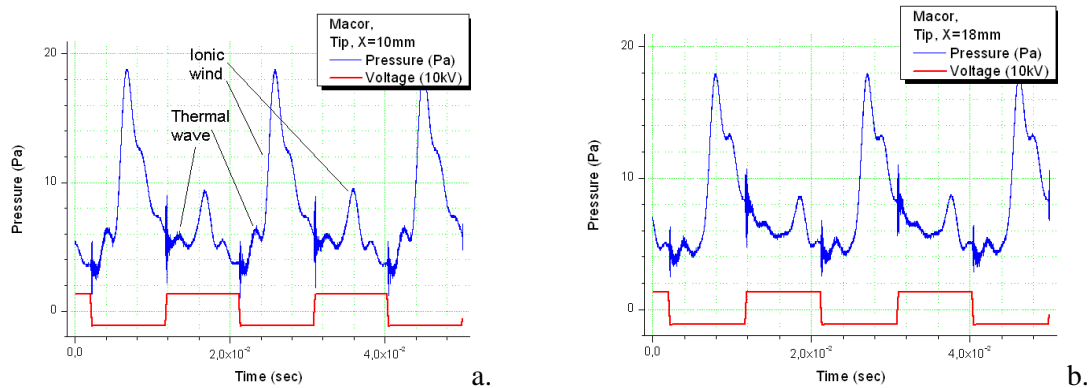


Fig.2. Pressure signal in Air at electrode with the tip, $X = 10$ (a) and 18 (b) mm.

To explain the features of SDBD behavior, measured and observed in this study in air and nitrogen, the results of numerical simulation and analytical estimations [7] have been used. The prospects of practical implementation of plasma technology for flow structure and sound control are discussed.

This data will be useful during actuator design for BL separation and transition control. The experiment was supported in part by Department of Mechanical Engineering of Princeton University. This work was also supported by Russian Foundation of Basic Research in the frame of project 10-08-01056a.

Keywords: plasma-based flow actuator, dielectric barrier discharge, control of flow disturbances

- [1] F. O. Thomas, T. C. Corke, et al, *AIAA Journal* 47, 2169 (2009)
- [2] E. Moreau, *J. Phys. D: Appl. Phys.* 40, 605 (2007)
- [3] C. L. Enloe, M. G. McHarg, Th. E. McLaughlin, *J. Appl. Phys.* 103, 073302 (2008)
- [4] U. Kogelschatz, *Journal of Physics: Conference Series*, vol. 257, 2010 IOP, p. 012015, 2010.
- [5] J. P. Boeuf, Y. Lagmich, Th. Unfer, et al, *J. Phys. D: Appl. Phys.* 40, 652 (2007)
- [6] S. Leonov, R. Miles, D. Opaitis, V. Soloviev *PHYSICS OF PLASMAS* 18, 6 (Oct), 2010
- [7] V. Soloviev, *J. Phys. D: Appl. Phys.* 45 025205 (2012)