



Comparative study of an atmospheric pressure helium plasma jet driven by unipolar nanosecond-pulses

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Introduction

Atmospheric pressure plasma jets (APPJs) have been widely used for biomedical applications for the last couple of decades. In this study, we present the properties of nonpolar pulse-driven APPJs which show different performances from those with sinusoidal driving voltages. Experimental investigation of APPJ includes optical emission spectrometry (OES) and the current-voltage characteristics. Also, the water contact angles on the PDMS with the variation of the control parameters are presented. AFM was used to get a better understanding of contact angle changes.

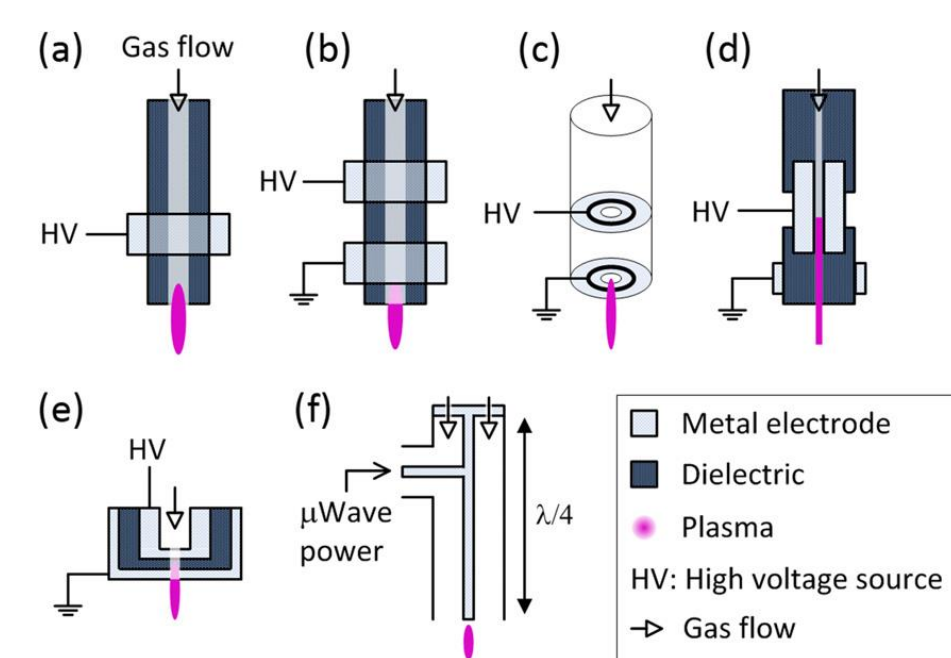


Figure 1. APPJ (atmospheric pressure plasma jet and construction)¹

Plasma jet introduction and experimental setting

Feed gas :helium

Inlet gas flow: 1~3 slm

Pulse voltage: 2 kV~ 3 kV

Frequency: 1~50 kHz

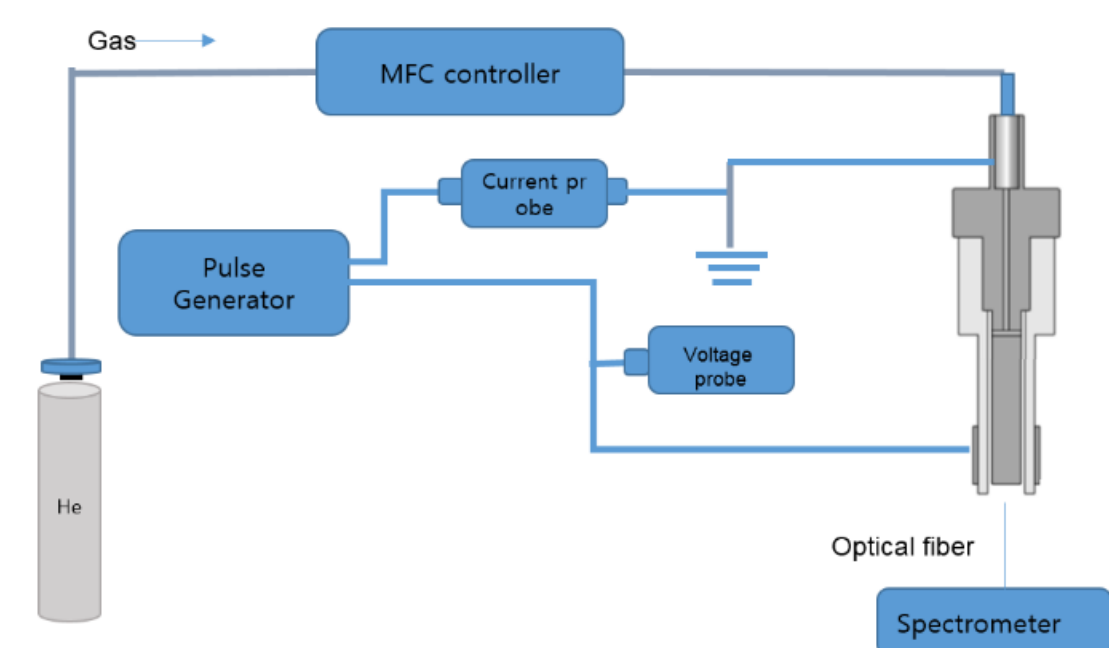


Figure 2. Experiment setting schematic diagram of DBD plasma jet

Discharge voltage and current waveform

Generally, the volume DBD can be characterized with a variable resistor, which connected with a capacitance in parallel. In unipolar pulse driven discharge, the variable resistor can be presented by a current source. With the equivalent circuit, some electrical parameters can be calculated with the following process [2]

$$i_g = \left(1 + \frac{C_g}{C_d}\right) i_t - C_g \frac{du_t}{dt} \quad (1)$$

$$i_d = \frac{C_g C_d}{C_g + C_d} \frac{du_t}{dt} \quad (2)$$

$$u_d = \frac{C_g}{C_g + C_d} u_t + \frac{1}{C_g + C_d} \int_0^t i_g(t) dt \quad (3)$$

$$u_g = \frac{C_d}{C_g + C_d} u_t - \frac{1}{C_g + C_d} \int_0^t i_g(t) dt \quad (4)$$

$$P_g = u_g \times i_g \quad (5)$$

Where C_d is the capacitances of the dielectric layer and C_g is the capacitances of gap. u_t is the voltage across the whole device and i_t is the total current. i_d is the displacement current across the whole circuit and i_g is the discharge current in the gap. u_d is the voltage on dielectric and u_g is the voltage across the gap. From eq.1 and eq.4 we can calculate the discharge current and discharge voltage.

Experimental Results

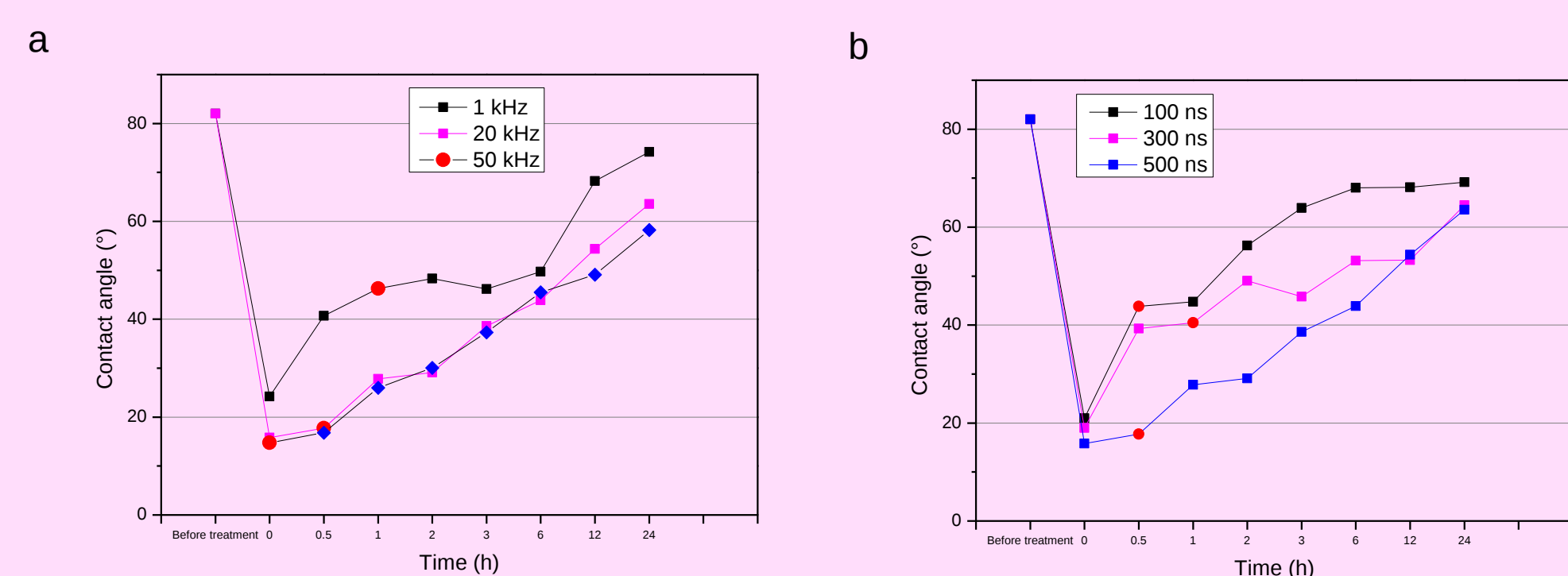


Fig.7. Contact angle measurement of the He plasma jet treated PDMS film based on time after treatment for the variation of: a) frequency; b) pulse width. Red points represent the AFM measurement time.

It shows plasma treatment has changed the hydrophilic of the PDMS film, which is not a permanent change. As time goes on, the film trends to restore its original hydrophilic. But the pulse power parameters still take an influence on the after treatment contact angle and the recovery of hydrophilic. We find that both frequency and pulse width affect the plasma treatment while frequency has an obviously greater influence on the treatment.

4) AFM measurement

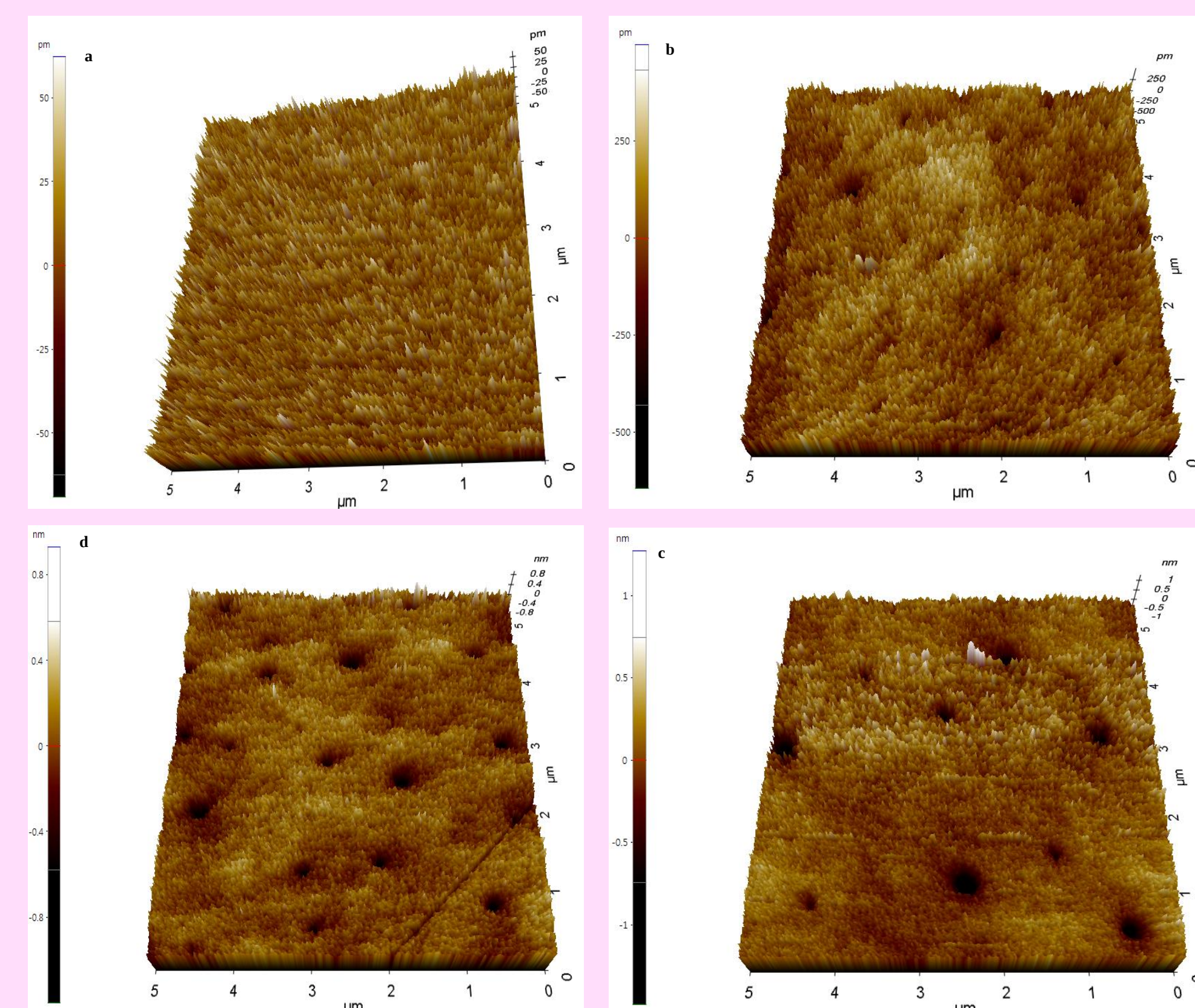


Fig.8. AFM pictures of the He plasma jet treated PDMS film for the variation of (a) Control; (b) 1 kHz; (c) 20 kHz and (d) 50 kHz.

As shown in fig.8, the surface of untreated film is very smooth with a roughness of 50 pm. After treatment, roughness reaches 250 pm and 500 pm and even to nm scale. Besides, holes generated in most cases after plasma treatment. But if we combine with all the hole numbers and hole size, we can obtain the conclusion that the surface get a bigger and bigger change as the increase of pulse width and repetition frequency.

Plasma treatment

PDMS film contact angle has been widely used to evaluate the plasma treatment [3]. In this experiment, the PDMS film with a thickness of 100 um was used as the treatment material. Distance from the jet nozzle to film was set as 15 mm and treatment time was set as 60 s. Contact angle was measured directly after treatment and by time after treatment with the surface analysis device (Phonix 150i)

The Atomic Force Microscope (AFM) was use to explore the change of surface shape of the treated film. AFM device takes about 15 minutes to scan an area of 5 um x 5 um for one film. So the AFM measurement wasn't taken exactly after treatment. The AFM measurement time is identified in fig.7(the red solid point represent the measurement time)

Experimental Results

3) Electrical parameters for a pulse

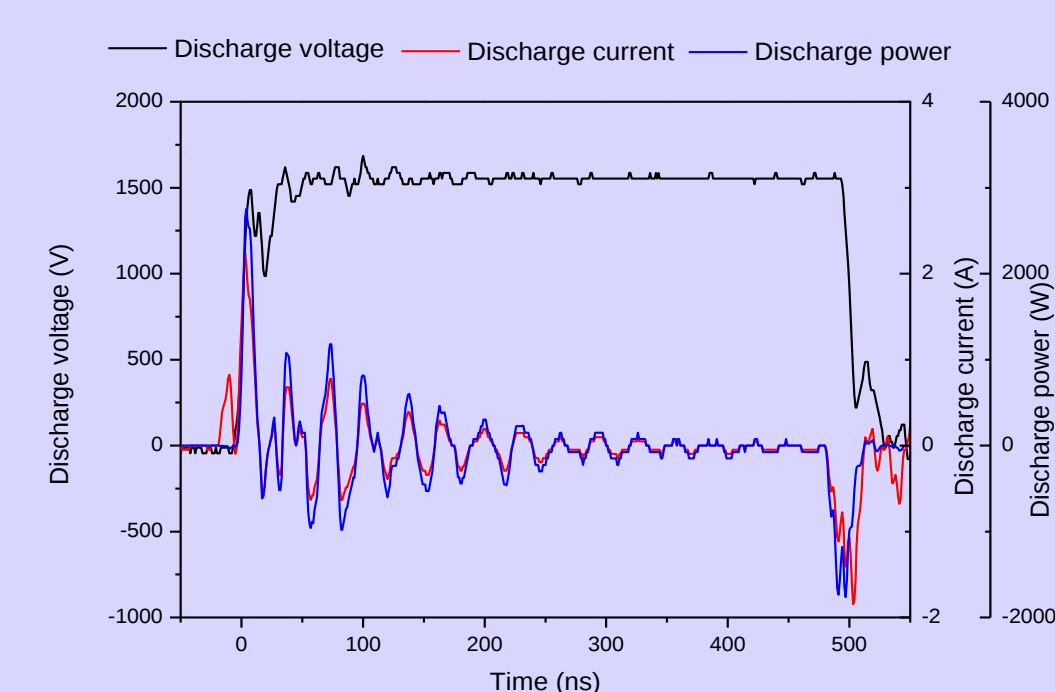


Figure 3. Electrical parameters for a pulse

Capacitance value used in this calculation was obtained from the former work, a sinusoidally driven plasma jet Lissajous figure, which was introduced in reference [4]. u_t and i_t was measured from the probe and oscilloscope. The calculated current- voltage curve can be seen as fig.3. The voltage across the gap is about 1.5 kV while the voltage across the whole device is 2 kV. From these parameters, we calculate the discharge energy per cycle.

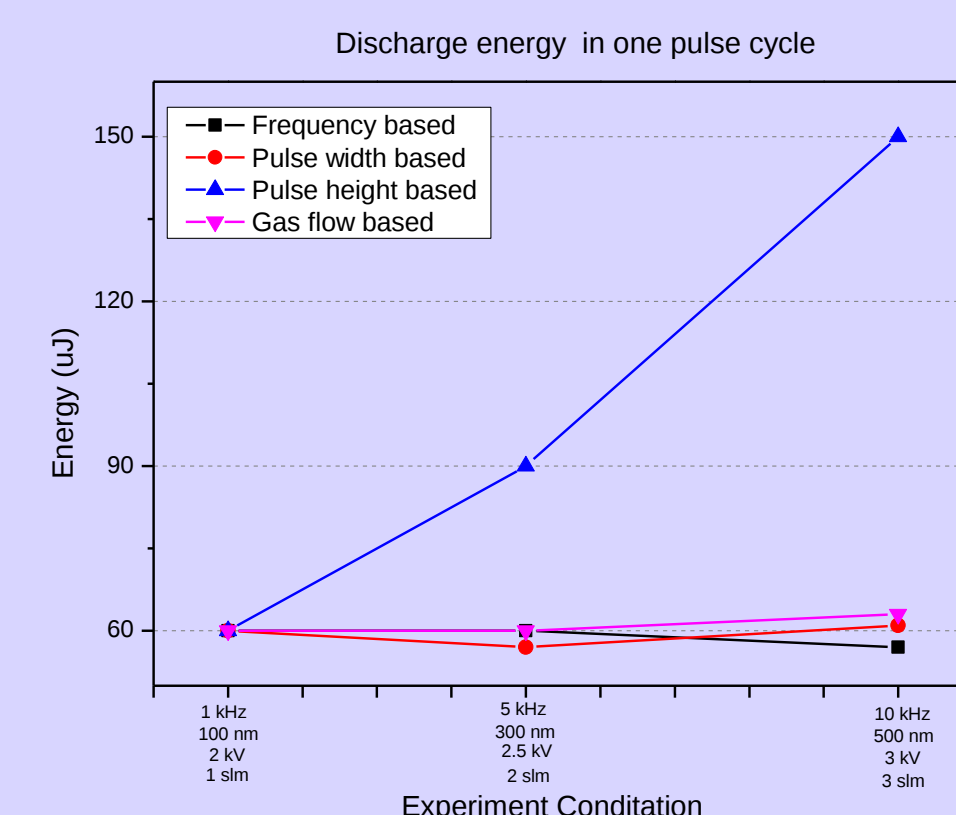


Figure 4. OES for argon and helium plasma based on different pulse width

Discharge energy was shown as fig.4, we can find that pulse height influence dominantly on the discharge energy per pulse as predicted. Frequency-based discharge energy does not show big changes in one cycle, but the power obviously increases with the repetition frequency. It is also consistent with the previous results. Considering that the discharge energy is almost stable, the increase of the repetition frequency will be the most intuitive way to get a stronger discharge.

2) OES measurement

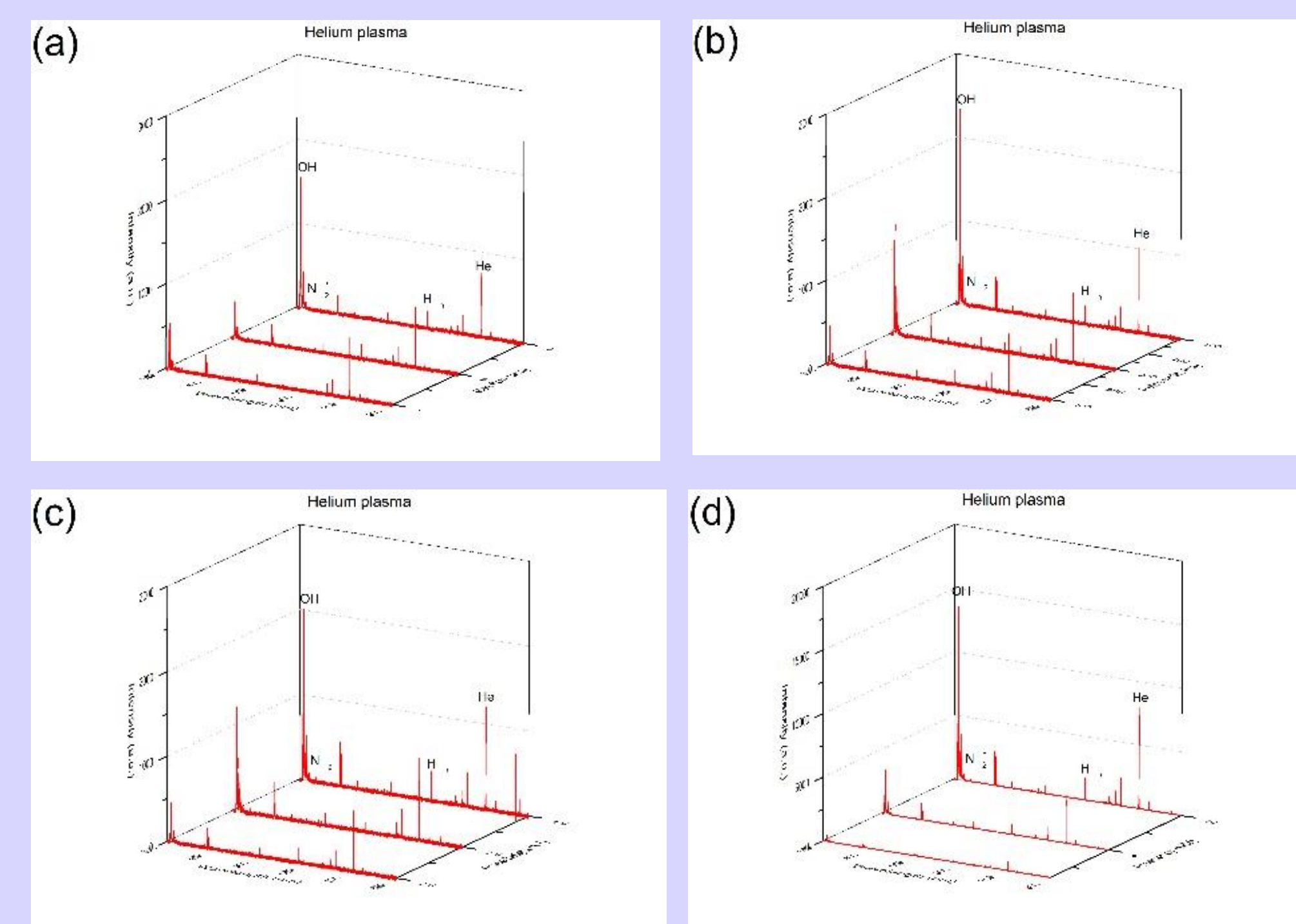


Fig.5. OESs of the He plasma jet for the variation of (a) the gas flow rate of 1, 2, and 3 slm; (b) the pulse width of 100, 300, and 500 ns; (c) the pulse height of 2, 2.5, and 3 kV; (d) the repetition frequency of 1, 5, and 10 kHz.

From fig.5 we can see various radical are generated such as OH, N+, and He. Note that for frequency case, the intensity scale is much larger than the other three cases. Generally, the intensities of the spectra show an increasing trend as the pulse parameters increase, which is also the same for the gas flow. The pulse repetition frequency shows a dominant effect on the magnitude.

3) Contact angel for plasma treatment of PDMS

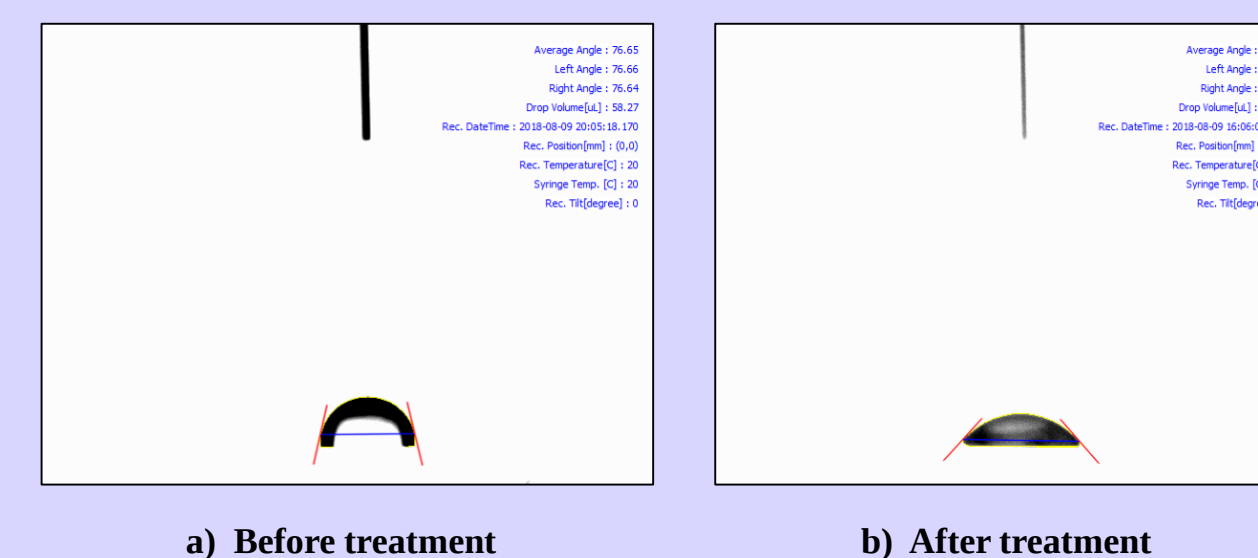


Figure 6. Contact angle of PDMS before and after plasma treatment

Summary

- ◆ Pulse height influence dominantly on the discharge energy per pulse while frequency-based discharge energy does not show big changes in one cycle, but the power obviously increases with the repetition frequency
- ◆ The driving frequency plays a dominant role in the formation of radical generation during the discharge process.
- ◆ From contact angle measurement, we can find that both frequency and pulse width affect the plasma treatment while frequency has an obviously greater influence on the treatment.
- ◆ From the AFM results, we find that holes generated in most cases after plasma treatment, besides, surface get a bigger and bigger change as the increase of pulse width and repetition frequency.

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