Optimizing energy efficiency for industrial application of pulsed corona gas cleaning techniques

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CONTROLLING THE ATMOSPHERIC GLOW STABILITY

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In this paper it is shown that through electronic suppression of the unstable plasma modes the atmospheric glow can be generated at high power density and in a variety of gases. It is argued that not the pre-ionization but the plasma stabilization is the key factor in atmospheric glow generation.

Key words: plasma stabilization, uniform atmospheric plasma

1 Introduction

Most of the atmospheric plasmas are generated in filamentary unstable form and the existence of atmospheric glow is a quite intriguing exception. It is widely believed that atmospheric glow generation is related to a large pre-breakdown pre-ionization [1-5]. This theory is based on the reasoning that pre-ionization would suppress the avalanches space charge and will eliminate the possibility of a filamentary streamer breakdown [1]. Nevertheless the link between pre-ionization and atmospheric glow generation it is still under debate. They are several experimental evidences that atmospheric glow can be generated with a negligible pre-ionization [6,7]. To our opinion not pre-ionization is the key factor in atmospheric glow generation but plasma stability. There is no plasma physics law forbidding the generation of an atmospheric glow *if the streamer breakdown does not occur.* However the generation of a *stable and uniform glow* at atmospheric pressure is rather improbable. Due to the large pressure and large collision rates a fast growth of instabilities due to large collision rates will occur. These instabilities will be slow damped (due to the slow diffusion) so a local perturbation will growth very fast and will remain localized generating a tendency of plasma to filamentate . As it will be argued in this paper atmospheric plasmas have a stable mode and a unstable mode. By suppressing the unstable plasma mode the atmospheric glow can be generated at high power density and for a large variety of gases.

2 Experimental

The plasma was generated in He, Ar, N_2 , Ar/O_2 , N_2/O_2 and air (gas flow speed 0.5-1 m/s), between two parallel electrodes (electrode gap 1 mm, plasma surface 60 cm^2). The discharge was operated in air surroundings or in a controlled environment. We estimate that at the standard flow conditions of 1 m/s there are hundreds of ppm of air due to the leaks in the reactor from the surroundings. In another set-up the purity of environment was strictly controlled by vacuuming the system up to $8*10^{-2}$ mbar and filling it afterwards with gas up to atmospheric pressure. In this case the impurities are estimated to be o filling it afterwards with gas up to atmospheric pressure. In this case the impurities are estimated to be of few ppm. No significant differences were noted in the plasma I-V characteristics or plasma uniformity and stability between the two set-ups. Glow generation was investigated using as surfaces in contact with plasma polyethylene naphthalene (PEN) , polyethylene teraphtalate (PET) , polyethtlene (PE) of 100-200 µm thickness , and alumina coated on metal (~500µm thick) .The high voltage (0.2-8 kV, 5-450 kHz) was applied to the electrodes using a system consisting of a computer controlled pulse generator and a power amplifier. The current and voltage waveforms were recorded through a computer controlled TDS 3034 B TEKTRONIX oscilloscope (sampling resolution 1 ns, bandwidth 350 MHz). The current flowing through the APG reactor was measured using (Tektronix CT-1 and TCP 202) current probes. In order to monitor the plasma uniformity the spatial distribution of the light emitted by the plasma was recorded using a DALSA Eclipse fast CCD camera (integration time 13µs).

3 Plasma instability

Plasmas at atmospheric pressure tend to be extremely unstable due to a critical combination of fast growth of perturbations and slow perturbation damping. The slow damping of perturbation is mainly due to the small diffusion coefficient at atmospheric pressure and thus of a slow diffusion of of ions, vibrationally excited molecules and metastables. The diffusion is so slow that a perturbation in the charge or excited species density will need milliseconds to diffuse over a millimeter. Due to the generation at large pd (pressure*gap) values plasma is extremely sensitive to thermal/ionisation instability [8,9,10]. It can be demonstrated [10] than due to changes in temperature a small perturbation in the current density will be substantially amplified :

$$\frac{d\ln j_{plasma}}{dt}=\frac{1}{1-\beta\left(\dfrac{d\ln j_{plasma}}{d\ln(E/n)}\right)}\Phi_0 \tag{1}$$

$\Phi o=\delta j_{plasma}/dtj_{plasma}$ is the initial perturbation in current density , and β is the feedback coefficient of the plasma temperature to the perturbation reflecting the increase of absolute temperature in percents when the plasma current increase with one percent.

The equation (1) may be rewritten as :

$$\frac{d\ln j_{plasma}}{dt}=\frac{1}{1-\beta\left(\dfrac{d\ln j_{plasma}}{d\ln(E/n)}\right)}\Phi_0=\frac{1}{1-\beta\dfrac{\frac{dI}{I}}{\frac{dV_{plasma}}{V_{plasma}}}}\Phi_0=\frac{1}{1-\beta\dfrac{R}{r}}\Phi_0 \tag{2}$$

where I is the plasma current, V_{plasma} is the voltage drop on plasma , r is the dynamic resistance of the plasma (dI/dV_{plasma}) and R is the plasma resistance (I/V_{plasma}). The ionization instability will growth very fast if :

$$\beta\frac{R}{r}>=1\Rightarrow\frac{r}{R}<=\beta$$

i.e if the ratio of dynamic to static resistance is low. Thus if the thermal/ionization instability is indeed a risk at atmospheric pressure one will expect that the IV characteristics of plasma will have a low ratio of the dynamic to static resistance. This is indeed the case. In all our experiments we observed that usually the atmospheric plasmas have a low ratio of dynamic to static resistance r/R. For example in Fig.1 the IV of characteristic of a plasma in Ar it is presented. In Fig.2 one can note that even He has at the end of the discharge a low dynamic resistance. Due to this instability the plasma will switch in a unstable mode [11].

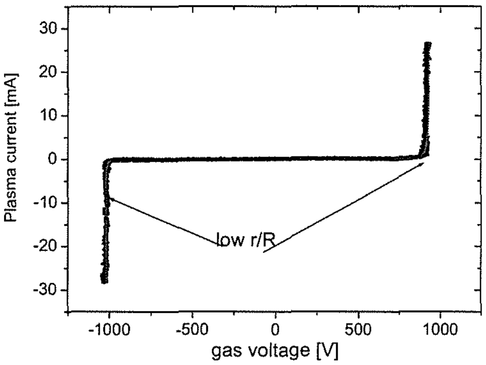

Fig.1 Ar plasma I-V characteristics
d=1 mm, f=12 kHz, PEN dielectric

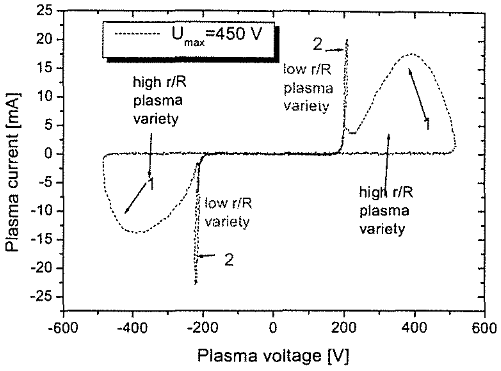

Fig.2 He plasma I-V characteristics
He f=10.8 kHz, d=1 mm, U_{max}=450 V

4 Plasma stabilization

The development of instabilities and of the filamentation must be prevented in order to generate the stable glow variety. The peculiar low *r/R* ratio of the unstable plasmas can be exploited in order to *suppress electronically this plasma variety*.[12,13] For example in Fig.3 the IV characteristics of a electronically stabilized Ar plasma is presented. One can note that to the contrary of the case presented in Fig.1 for most of the current pulse duration the electronically stabilized plasmas have a *r/R* ratio of order of unity. Moreover the spatial distribution of the light emitted by the plasma is not anymore filamentary but uniform (see Fig.4).

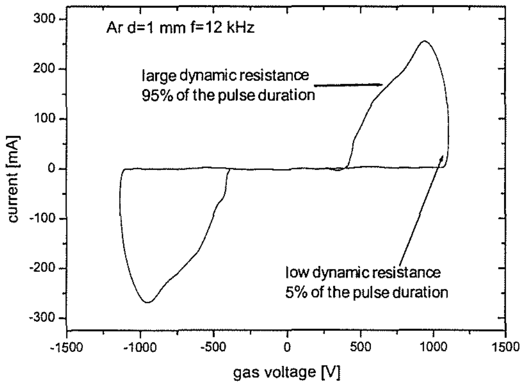

Fig.3 I-V characteristic of a stabilized Ar plasma
d=1 mm, f=12 khZ, PEN dielectric

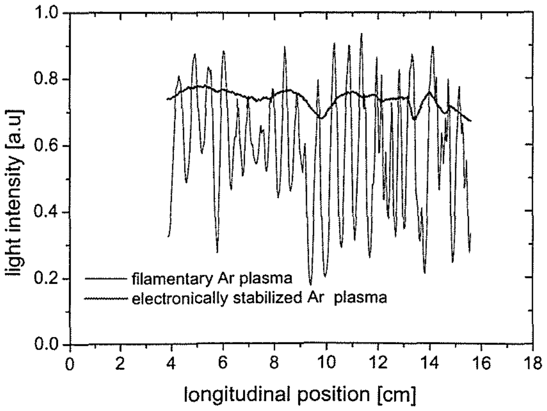

Fig.4 Spatial distribution of a filamentary and electronically stabilized Ar plasma

Commonly atmospheric glow can be generated only in He or in or very pure nitrogen and at relatively low power density. By using electronic stabilization uniform atmospheric plasma by adding a large concentrations of oxygen (up to 15%) and at large power density (up to 5 W/cm^2).

5 Conclusions

The thermal/ionization instability is the key factor, which is preventing the atmospheric glow generation. Excepting He atmospheric plasma generation requires the suppression of the unstable plasma modes. Several dedicated electronic circuits were developed for this purpose. Only in this way we succeeded to generate the atmospheric glow at high power density and for a large variety of gases.

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