Back and forth directed plasma bullets in a helium atmospheric pressure needle-to-plane discharge with oxygen admixtures

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Abstract
A sinusoidally driven needle-to-plane discharge in flowing helium at atmospheric pressure was investigated by means of electrical, optical and spectroscopic (VUV, UV and OES) measurements. ‘Bullet-like’ behaviour of the discharge was observed and investigated with special interest towards velocities and size of the ‘forward bullet’. The influence of the discharge gap and oxygen admixture on the discharge properties was analysed. The focus of this paper is on experimental results, showing discharge development within six phases. Among these, four types of bullets are observed with respect to the direction of the gas flow and applied voltage polarity. Temporally resolved photography shows the formation of an atmospheric pressure glow discharge subsequent to the propagation of the ‘forward bullet’. For the greatest gap of 15 mm, the plasma activity was restricted towards the positive voltage polarity. The discharge development under the oxygen admixture showed a delayed current pulse for the negative voltage slope, with a steep rising flank. We conclude that the main movement of the bullets in our setup does not depend on the gas flow but on the electrical field direction.

(Some figures may appear in colour only in the online journal)

1. Introduction

The increasing number of reports and scientific publications related to plasma medicine and its benefit and risk estimation studies reflect the importance of plasma technologies used in this field [1–4]. Atmospheric pressure plasma jets are rapidly gaining importance as tools for plasma processing since they are technologically simple, environmentally friendly and very economical [5, 6]. Applications of these plasmas include deposition [7, 8], surface modification [8–11], decontamination and sterilization [12–15], trials in cancer therapy [16, 17] and wound healing [18–23].

Different configurations have been proposed [12, 24–26] for the generation of atmospheric pressure plasma jets which, despite some differences (power source, electrode configuration, working gas), all present a common characteristic: the plasma effluent is not continuous, but is composed of individual bright packets, mainly known as ‘plasma bullets’ [27, 28]. These bullets propagate at high velocity over long distances. Also, under specific experimental conditions, it was found that a bullet, seen end-on, can be homogeneous or inhomogeneous (e.g. ‘donut’ shape) [27, 29, 30]. The velocities for ‘bullet-like’ structures were reported to be from 10³ m s⁻¹ [30–32] up to 10⁵ m s⁻¹ [28, 33–37].

However, the nature of the physical processes responsible for the launching and propagation of these bullets remains unclear. Different models have been proposed to explain such phenomena, but none of them seems to be able to predict all experimental observations in detail. Lu and Laroussi [28] suggested a streamer model based on photoionization to
Maximum bullet speeds coincide with typical values for ‘streamer’ propagation. However, bullet speeds during the early phase of propagation were found to be clearly below the predicted values from ‘streamer’ simulations but could be reproduced by ion drift calculations.

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