Visualising gas heating from an RF plasma loudspeaker

How to cite:

For guidance on citations see FAQs.

© 2010 The Authors

Version: Version of Record

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online’s data policy on reuse of materials please consult the policies page.
Introduction

In an electro-acoustic transduction mechanism, an ac modulation (here in the audio frequency range) of the electric field in an atmospheric pressure air plasma gives rise to a rapid increase in the gas temperature and dimensions of the gas volume. As in natural lightning, the rapid expansion in the ionised column through the air produces external pressure variations at the modulation frequency.

Spatial and temporal measurement of the gas temperature can identify the nature of the thermal expansion and provide a direct approach to understanding its relationship to the sound pressure wave that is generated. However, the established method through spectroscopic measurement of rotational line emission from nitrogen molecules is limited to the current main channel where relaxation and subsequent optical emission of the excited nitrogen molecules occurs. The wider picture is revealed through the use of the Sclieren method where the refractive index gradients caused by gas heating in the plasma are imaged.

Experiment and model

An atmospheric pressure, air plasma is generated using a solid state Tesla coil operating at a resonant frequency of 325kHz. Upon breakdown, the plasma is sustained at a voltage of 4-5 kVp with a conduction current, \( I_{con} \), between 1-10mA. The rotational temperature, \( T_{rot} \), has been measured previously through spectroscopy and lies in the range 2600-3400K for the conduction current given previously. The electron density, calculated from the conduction current, is in the region of \( 3 \times 10^{10} \text{ m}^{-3} \).

The plasma was imaged using a dual field lens system. A 40W tungsten halogen bulb with a 632nm filter provides a narrow band monochromatic source. The area covered by the CCD was 24mm\(^2\) with a pixel resolution of 28pm. A razor, mounted on a travel stage with 0.01mm resolution, was used as the knife edge, and for a 2% image cut-off and \( F = 750 \text{ mm} \) for the imaging lens, \( t_p \), the minimum detectable deflection angle, is approximately 1\(^\circ\), equivalent to a change of 100K in the gas temperature.

The model was adapted from a convection stabilised DC discharge, with vertical and axial symmetry. The gas density was calculated using the relation

\[
\rho = \frac{p}{RT} = \frac{p}{M \cdot T},
\]

where \( M \) is the molar mass of the gas, \( R \) is the ideal gas constant, and \( T \) is the gas temperature. The model includes the balance equations for the number densities of \( N, O, NO \) and electrons. The model was adapted from a convection stabilised DC discharge, with vertical and axial symmetry, equivalent to a change of 100K in the gas temperature.

Calibration

A 1Ω resistor drawing a current of 6mA was used as reference heat source to calibrate the system. The temperature profile of the resistor was measured using a thermocouple. Although the temperatures compare well at the surface of the resistor and drop off to a common background temperature, the Sclieren profile identifies additional structure between 2.5 mm from the resistor surface. This may highlight regions of convective heating that may not be detected by a thermocouple due to its response time. Also, the high cut-off level used here leads to distortion effects around the resistor which impacts on the calculation of the radial position and an uncertainty of \( -1 \text{ mm} \) should be applied.

Results

The degree of knife edge cut-off is taken as the ratio of unobscured width to total width of the source image and its effect for several cut-off levels can be seen above. Increasing the cut-off leads to increasing contrast changes. The dark regions above 98% cut-off results from strongest deflections that cause the displaced image to move entirely onto the knife edge. As a result, a change in image illumination is no longer produced; this effect is known as underbranching\(^{(1)}\).

Acknowledgments

The authors gratefully acknowledge the support of Bowers & Wilkins Group Ltd. in the funding of this work.

References