Breakdown of order in a self-organised barrier discharge

R. Wild[1(*)], L. Stollenwerk[1]

[1] *Institute of Physics, Ernst-Moritz-Arndt University*
17489 Greifswald, Germany
(*) wild@physik.uni-greifswald.de

In this contribution, the breakdown of a self-organised hexagonal pattern in a dielectric barrier discharge at voltage reduction is investigated. The recorded luminescence distribution is examined using the triple correlation function. It turns out that, as the voltage is reduced, the pattern bifurcates supercritically from the hexagonal structure to a random distribution of the filaments. In doing so, a fixed chronology in the degradation of angular and radial order seems to be present.

Laterally extended dielectric barrier discharges have been found to produce self-organised lateral structures. The discharge breaks up into a number of filaments that may show a collective behaviour yielding higher ordered structures, e.g. hexagonal patterns [1].

The presented discharge is produced in a setup consisting of two glass plates (thickness $a = 0.7$ mm) at a fixed distance of $d = 0.5$ mm from each other (Fig. 2) . Both have been prepared with an ITO layer on the outer side to permit a lateral observation of the structure while providing the necessary supply voltage of $U = 330...400$ V. The discharge cell is mounted in a closed chamber that is filled with helium at a pressure of $p = 200$ hPa for each experiment.
The lateral structure of the discharge is acquired with a Proxitronic image intensified camera that has a resolution of 512×480 px. An exposure time of $200\,\mu$s was used.

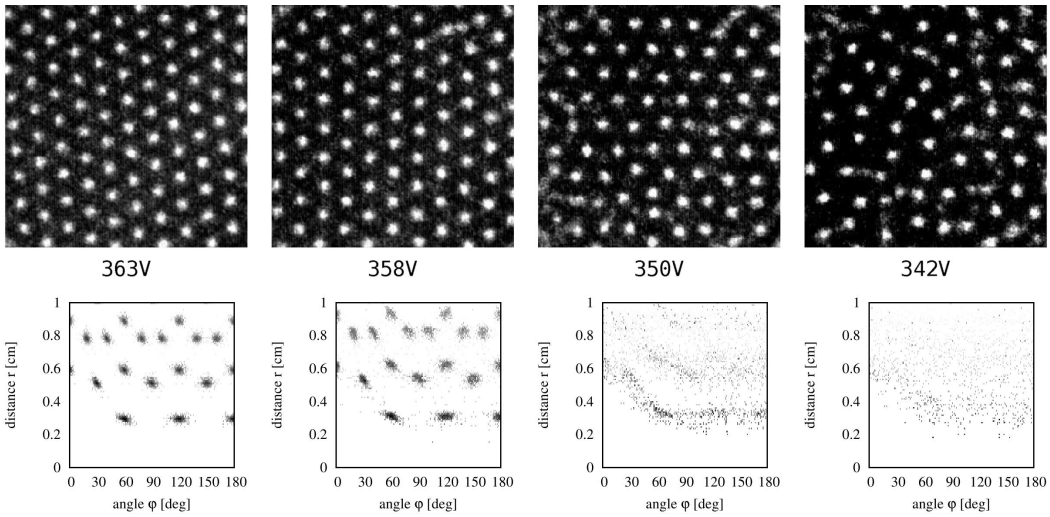

Fig. 1: Light density distribution images at voltages near the bifurcation point and their corresponding triple correlation functions $y(r,\varphi)$. $f = 80$ kHz sinusoidal, $p = 200$ hPa, Helium, without gas flow, exposure time 200 μs, TCF: r' is integrated to the nearest neighbour distance.

The amplitude of the supply voltage is stepwisely reduced from 400 V to 330 V. At a voltage of $U = 400$ V, the pattern consists of around 130 hexagonally arranged filaments. This pattern stays stable down to $U \approx 360$ V, where the structure starts to decay. As the voltage is furtherly reduced, the arrangement of the filaments becomes progressively random. During the entire process, the number of the filaments is reduced. Closely above the burning voltage, the discharge consists of only a few filaments.

The transition is examined using the triple correlation function. This function evaluates the position of any filament triple (i, j, k) and issues a probability distribution $y(r,\varphi)$ for one filament of finding a second filament at a distance $r = |\overline{jk}|$ and an angle of $\varphi = \text{angle}(i,j,k)$. For more details, we refer to [2].

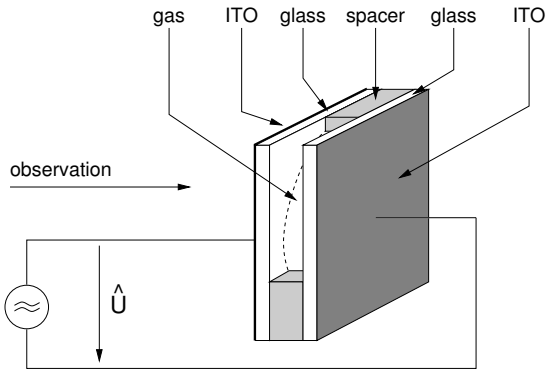

Fig. 2: Schematic of the discharge cell setup. The cell consists of two glass layers with a thickness of 0.7 mm each and at a distance of 0.5 mm to one another. Both have been roughened at the gap side and ITO covered at the outer side.

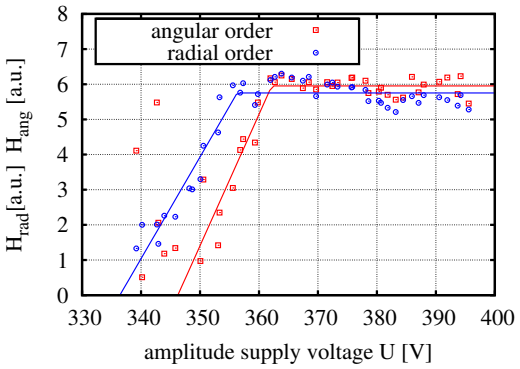

Fig. 3: Analysis of the transition from hexagonal to random pattern. Considered are the ratios of the $y_{60} = y(d_0, 60°)$ peak to the mean background in angular and radial direction according to eqn. (1) and (2), respectively.

In Fig. 1, the TCF are each shown next to their corresponding luminosity distribution images for selected voltages. Qualitatively, the transition from hexagonal to random pattern starts with a degradation of the angular order of the filaments. It is followed up by a decay of the radial order. At the end of this transition, the angular order of the filaments has completely dissolved, whereas the radial order is conserved to a small degree, as a small modulation stays visible. This conservation can be explained considering the filaments inhibitory interaction on close distances to each other [3], which results in a minimum neighbour distance.

In order to characterise the transition quantitatively, a measure of order is introduced. The main idea is to define the respective order as the relative height of the TCF peak at $\varphi = 60°$ and at nearest neighbour distance $d_0 \approx 0.33\,\mathrm{cm}$, which is most characteristic for the hexagonal pattern. Hence, the quantities are defined as ratio of the height $y_{60} = y(d_0, 60°)$ to the mean background in angular and radial direction, with

$$H_{\mathrm{ang}} = \frac{y_{60}}{< y(d_0, \varphi) >_\varphi} \qquad (1)$$

$$H_{\mathrm{rad}} = \frac{y_{60}}{< y(r, 60°) >_r} \qquad (2)$$

Fig. 3 shows the order analysis using H_{ang} and H_{rad} for the previously observed transition. Principally, both plots display the same behaviour: at high voltages the measure of order remains nearly constant. For decreasing voltages occurs a sudden change of the measures slope, and the measure of order decreases. For very low voltages, the peak y_{60} vanishes in the noise. This is due to low order and additionally due to a decreased number of filaments. Hence, H_{ang} and H_{rad} are not meaningful anymore. The transition from a nearly constant H_{ang} or H_{rad} to a decreasing order is rather abrupt, so obviously there is a bifurcation from an ordered to an unordered system via a *supercritical bifurcation* [4]. In all measurements, the bifurcation point for the radial order $\hat{U}_{\mathrm{b,rad}}$ is at lower voltages than the bifurcation point for the angular order $\hat{U}_{\mathrm{b,ang}}$, which confirms the previously qualitative observation.

This work has been funded by the Deutsche Forschungsgemeinschaft, SFB-TRR 24, B14.

References

[1] Kogelschatz U, Eliasson B and Egli W 2003 *Plasma Chem. Plasma Process.* **23** 1-46

[2] P. Ludwig, H. Thomsen, K. Balzer, A. Filinov, M. Bonitz, *Plasma Phys. Control. Fusion* **52** (2010) 124013

[3] L. Stollenwerk, *New J. Phys.* **11** (2009) 103034

[4] P. Manneville, *"Dissipative structures and weak turbulence", Springer Verlag* **457** (1995) 257-272