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Study of Micro Glow Discharges as Ion Sources

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Abstract

We are developing a micro ionizer as the ion source in a miniaturised spectrometer-like gas analyser. Most important qualities are low price and operation at atmospheric pressure. The application of DC glow discharge in micro systems was studied by performing discharge and microplasma experiments in a vacuum system. Sparking, oscillating glow discharges, and eventually stable DC glow were observed. With 1 and 3 µm gaps, stable glow was achieved at atmospheric pressure in Ar and N_2 respectively. Glows were less stable in dry air.

Introduction

Mass spectrometry is a commonplace method for high precision gas analysis in laboratories. It works by ionizing a sample gas, filtering the ionized gas molecules according to their mass/charge ratio, and detecting the ions that pass the filter. For an envisaged hand held device, we are developing a micro ionizer. Most important target qualities are low price and operation at atmospheric pressure. Some options for the ionizing principle were studied: Electron impact ionization (EI), corona discharge, glow discharge (using either DC plasma or RF plasma which is capacitively or inductively coupled) and field ionization (FI). FI was tested [1] and discarded. Now the application of DC glow discharge in micro systems is being studied in detail. The advantage of DC glow discharge is the technical simplicity.

Devices and Measurements

The devices we used for our measurements were microstructured on fused silica and pyrex wafers. The planar electrodes consisted of a 300 nm thick metal layer. Pt and Au were used as electrode materials on a 10 nm thick Cr adhesion layer. The fused silica substrate below Pt electrodes was 5 to 10 µm deep dry etched to obtain free standing electrode edges. The substrate below Au electrodes was not etched. Fig. 1 shows an example for 10 µm gap Pt electrodes.

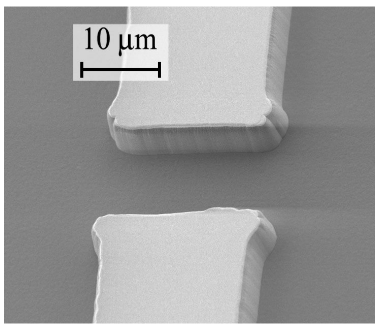

Fig. 1. 10 µm gap between two 300 nm thick Pt electrodes on 5 µm deep dry etched fused silica.

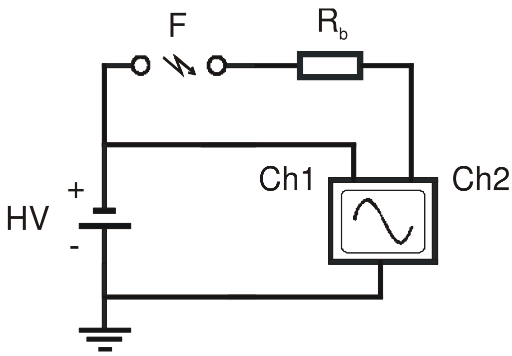

Fig. 2. Scheme of the circuit used for discharge experiments. F: discharge gap, R_b: ballast resistor, HV: high voltage source, Ch1/2: input channels of the oscilloscope.

The devices were placed in a vacuum system that allowed control of the surrounding gas type and pressure and which had a window for observation of the discharges. A ballast resistor of 100 MΩ protected the equipment and controlled the discharge. Other ballast resistors (10-1000 MΩ) were tested but gave less good results. The electrical scheme of the circuit used for the measurements is illustrated in Fig. 2. During a typical experiment the voltage was slowly increased from 0 V to breakdown. If at first there was only a small current pulse, we increased the voltage further until continuous sparking or glow discharge appeared. Breakdown in our experiments was clearly signified by a current jump from "0" to µA level. It resulted either in sparking or glow, depending on the experimental conditions.

Some studies of electrical breakdown in small gaps, where Paschen's theory is not applicable, have been done before [2, 3]. Results were not conclusive and no simple theory has been found yet. Fig. 3 illustrates the breakdown voltages, V_b, found in our own measurements in Ar and N_2. The lowest V_b we measured was about 260 V in Ar. In N_2 the lowest V_b was 320 V over a 5 µm gap at about 10 hPa. Therefore our V_b remained above the minimum sparking potentials for Ar (137 V) and N_2 (251 V) given by Naidu et al. [4]. Torres et al. [2] measured much lower breakdown voltages in gaps below 2 µm, while Germer's [3] measurements down to 1 µm agree better with ours. Only below 1 µm Germer sometimes observed breakdown at low voltages down to about 50 V at 250 nm.

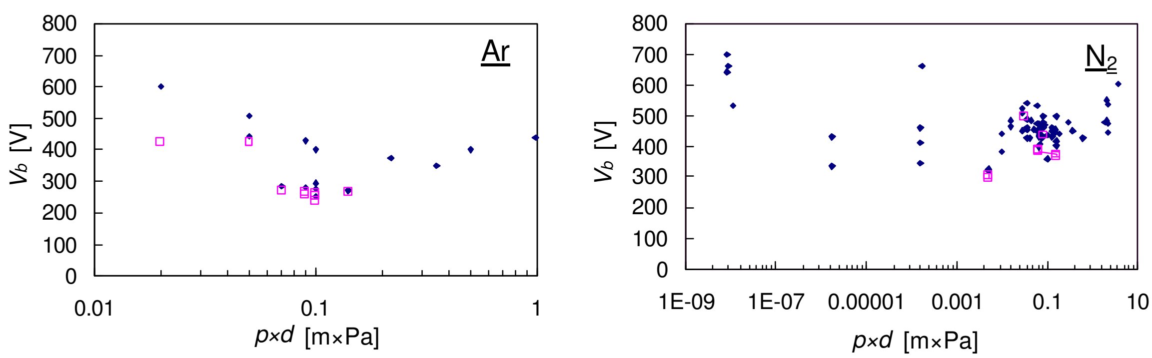

Fig. 3. Breakdown voltages over $p \times d$ (pressure × electrode distance) values of our breakdown measurements in Ar and N_2. 1 µm < d < 50 µm. Squares indicate points where a stable glow turned off when decreasing V. The pressure measurements in Ar were inaccurate.

We tested electrode gaps of 1 to 50 µm at pressures of 10^{-3} to 1.7×10^5 Pa in Ar, N_2, and dry air. Most measurements were done in N_2, because we had no means of measuring low pressures of Ar accurately. At atmospheric pressure we obtained stable DC glows in Ar using 1 µm gaps and in N_2 using 3 µm gaps. In N_2, glow was observed approximately in the range from 0.001 to 10 m×Pa in gaps from 3 µm to 50 µm. The pressure could not be increased sufficiently to obtain glow in a 1 µm gap. A noteworthy observation was that a glow just turned off when pressure was decreased below a certain level, but increasing the pressure above a certain level usually resulted in sparking. In dry air we achieved less stable glow.

When the cathode is not insulated, a glow spreads across its surface. The glow area in our experiments decreased with increasing pressure and increased with gap voltage. Such distributed glows oscillated with high amplitude (50 to several 100 Hz), see Fig. 4 (a).

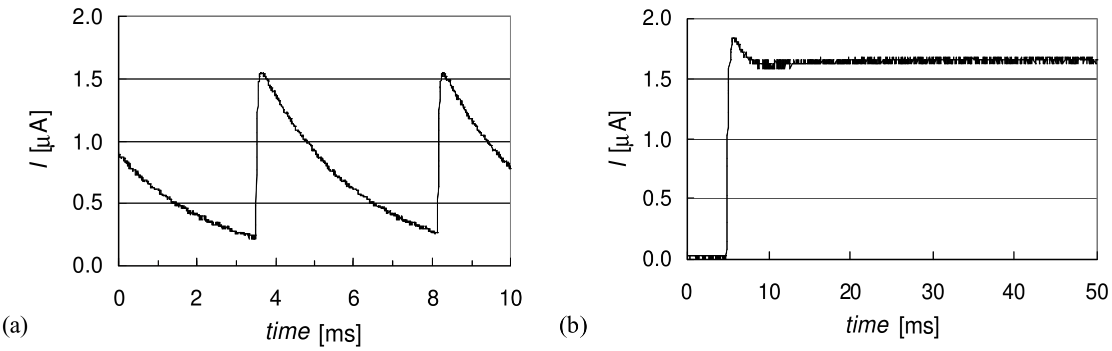

Fig. 4. (a) Typical oscillation of a cathode glow when the cathode is not insulated. Applied voltage: 409 V. (b) Ignition of a steady glow with an insulated cathode. Applied voltage: 536 V; gap voltage: ~370 V. In both cases: Gas: N_2; electrode gap: 10 µm; pressure: ~100 hPa.

To confine the glow to a small area near the electrode gap, we eventually insulated cathodes except for a small spot near the gap. Glows with insulated cathodes showed much less or no oscillation, see Fig. 4 (b).

With Pt electrodes, glow discharges were maintained for hours without significant current changes or electrode deterioration. During our experiments with Au electrodes, the cathodes were sputtered away quickly and deposited metal lead to a short circuit between the electrodes within less than a minute.

Discussion & Conclusions

There is only a limited range of $p\times d$ (p: pressure, d: electrode distance), where a glow discharge is possible. The smaller d, the greater the necessary p, in order that the sheath thickness (*Debye length*) of a glow can be thinner than the electrode distance. Above the maximum $p \times d$, electrons cannot reach sufficient energy between two collisions unless the gap potential is so high that it causes sparking. We did not endeavour to *calculate* the glow range. We fabricated functional DC glow ionizers, from which we conclude that such micro-devices may be suitable for application in a hand held gas analyzer regarding their small size and low power consumption. But stable operation could not be maintained for more than a few hours, which we believe to be mainly due to sputtering of the cathode (see also [5], where Eijkel et al. report the same problems in a similar micro glow discharge system). We might improve on this point by using electronics to control the discharge current, especially during ignition of a glow, but since the ionizer is supposed to be used in a rather aggressive environment, achievement of good continuous long-term performance appears doubtful. Therefore the option of RF discharge is now being considered as well.

Acknowledgements

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