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ELECTRICAL PROPERTIES OF PULSED GLOW DISCHARGE

Two new aspects

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Abstract. At the application of pulsed glow discharge (PGD) a transient power of several kW can be reached. This leads to a significant increase of the excitation and ionization efficiency of the sputtered sample atoms. Moreover, with pulsed mode temporally resolved optical emission spectrometry (OES) and mass spectrometry (MS) deliver additional information about the chemical bonds (Harrison 1998, Bengtson et al. 2000, Hang et al. 1996, Klingler et al. 1990, Lewis et al. 2001, Jackson and King 2003).

However, the practical application of pulsed glow discharge (PGD) requires an understanding of the processes taking place in the pulsed system. There are some publications, where attention was paid on the voltage current characteristics and the current signal shape of PGD (King and Pan 1993, Lewis et al. 2003). Nevertheless more attention should be paid on the electrical properties of the PGD. In this work the shapes of current, voltage and emission intensity signals, obtained with two different pulse generators are compared.

For better understanding of processes, taking place in the discharge the knowledge of the gas temperature is very important. Several authors have mentioned that heating of the cathode leads to changes of the voltage current curve, mainly a decrease of the current at the same voltage. This can be explained by a lower gas density at the same pressure but at higher temperatures (Chenlong et al. 1999, Tian and Chu 2001, Kasik et al. 2002). This phenomenon gives an approach to estimate the gas temperature of the plasma.

1. INVESTIGATION OF VOLTAGE CURRENT AND EMISSION INTENSITY SHAPES

1. 1. EXPERIMENTAL

For direct current (dc) and pulsed dc measurements an 8-mm Grimm type source from "Spectruma" with floating anode was used.

Two power supplies with significant difference in the electronic circuits were compared. "RUP3-3a" unlike the "IRCO M3kS-20N" has an additional high voltage switch, which discharges the load after the termination of the pulse.

1. 2. VOLTAGE AND CURRENT SIGNAL SHAPES

The voltage and current signal shapes during the pulse were compared for a generator with and without second switch ("RUP3-3a" and "IRCO M3kS-20N"). It is apparent that differences in the electronic circuit lead to differences in the current and voltage signal behaviour (Fig. 1).

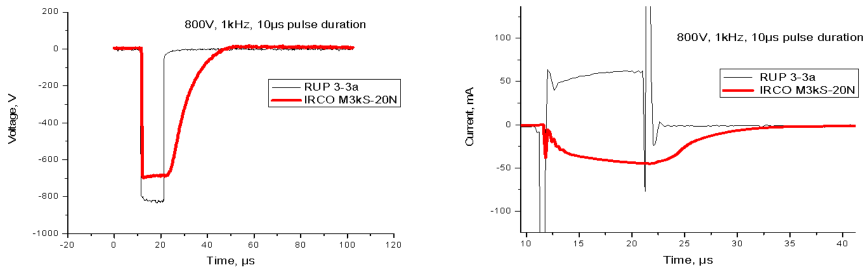


Figure 1: Voltage and current shapes during the pulse (the current of RUP3-3a is inverted for better presentation).

During the pulse at "RUP3-3a" first switch is on and second is off. To terminate the pulse the first switch is turned off, but at the same moment the second is turned on and discharges the residual load charge. Therefore there are no voltage and current signals after the termination of the pulse.

In the case of "IRCO M3kS-20N" the capacity of the pulsed system caused residual current after the pulse termination. Therefore the voltage and current signal disappears gradually and means that the plasma still exists.

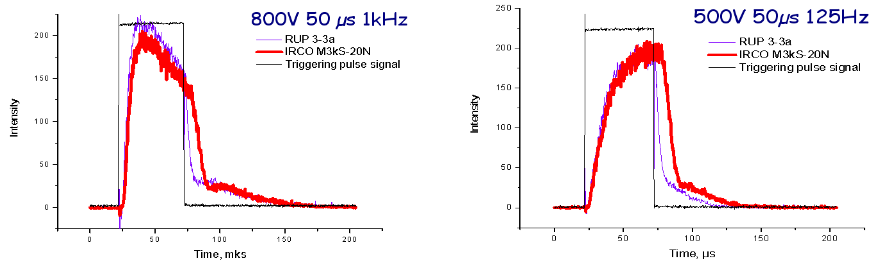
1. 3. LIGHT EMISSION SIGNAL SHAPES

The light emission of Ar I (696,54 nm) during the pulse time was measured. The emission from the GD cell was delivered through an optical fiber to the monochromator "SPEX 270M" from Jobin Yvon. The signal from the monochromator "SPEX 270M" was directed to the high speed low-noise current preamplifier "SR 570" from Stanford Research and then to the oscilloscope. In Fig. 2 the emission using "RUP3-3a" and "IRCO M3kS-20N" is compared. It was observed that the behaviour of current and light signals is similar. When the "RUP 3-3a" generator is used, the second switch discharges the cell after the pulse termination. This leads to the sharp fall of current and emission signal. In case of "IRCO M3kS-20N" power supply the residual charge in the system is not discharged after the end of the pulse. This means that the plasma doesn't disappear after pulse termination and still emits light.

It was found out that with decreasing voltage the light emission shapes are changing. Mainly, the maximum of intensity is moving to the end of the pulse (Fig. 2(b)).

The emission shapes from Fig. 2(b) are products of averaged signals from 32 pulses. If no averaging is used and the emission of one pulse is recorded, one will see the following picture (Fig. 3).

In the case of the generator without second switch ("IRCO M3kS-20N") the maximum of intensity appears after pulse termination, in contrast to "RUP 3-3a", where the second switch removes all signals after the pulse.



(a) (b)

Figure 2: Emission intensity signal shapes under normal (a) and low (b) conditions.

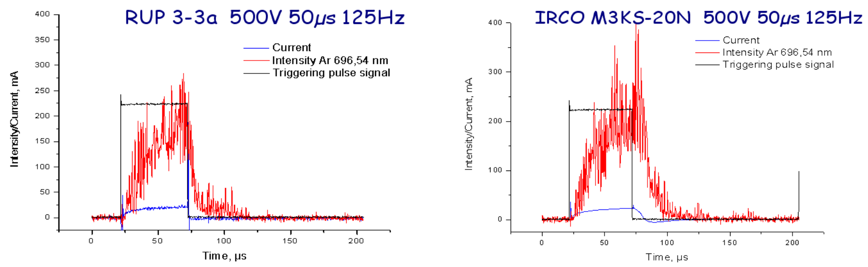
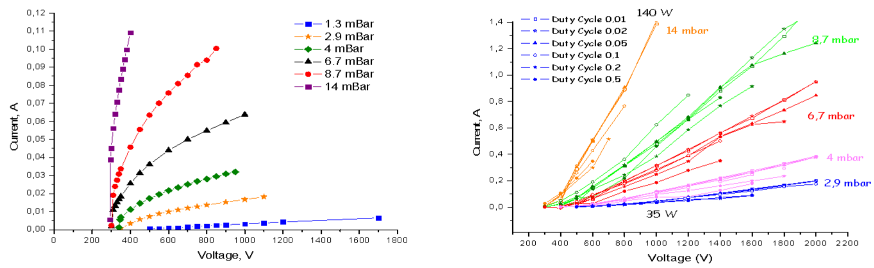


Figure 3: Emission intensity shapes of single pulses measured under low discharge conditions.

2. VOLTAGE CURRENT CHARACTERISTICS AS A THERMOMETER

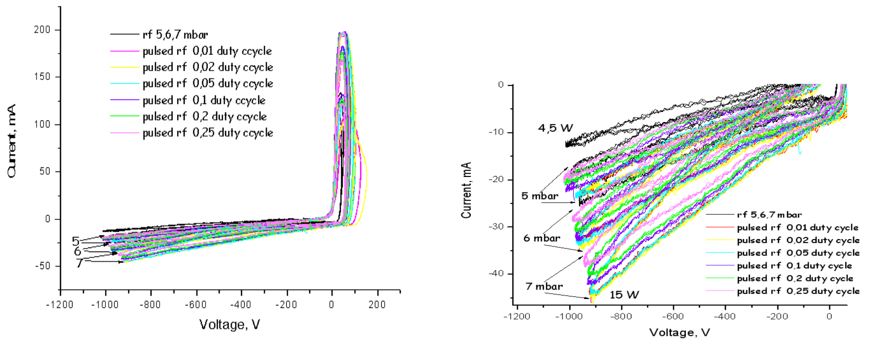
Electrical current in the dc and radio frequency (rf) mode was measured as function of the discharge voltage under different pressures. In dc and rf pulsed mode the influence of repetition frequency and pulse duration was additionally investigated. The current signals were averaged during the first 10 μs (for the dc pulsed mode) and the last 1 μs (for the rf pulsed mode).



(a) (b)

Figure 4: Voltage current characteristics of the (a) dc and (b) pulsed dc discharges.

For rf and pulsed rf measurements a special free-standing Grimm-type source with 4 mm anode and a free-running rf generator (Forschungstechnik IFW 3,37 MHz) was used. The instantaneous current and voltage signals were measured by integrated current and voltage probes (unique measurement system, developed at IFW Dresden) (Wilken et al 2003).



(a) (b)

Figure 5: Voltage current characteristics of the rf and pulsed rf discharges.

Changing of the current amplitude with the duty cycle can be explained by the influence of discharge power on the temperature of the gas. When the duty cycle increases the mean power consumption increases too, what leads to a heating of the plasma. In this work it was assumed that the different temperature of gas and thus different discharge gas concentrations are the main reason for the observed changes of the V-I characteristics. Processes like different secondary emission yield at the sample surface caused by temperature changes of the sample or changing concentration of the sputtered material in the plasma are considered as less important. Mainly, under constant pressure according to the thermodynamic law p=nkT an increase of the gas temperature leads to the decrease of Ar atom concentration and therefore of the current.

This phenomenon gives an approach to the discharge temperature estimation. Each V-I curve with the same slope is characterised by a certain Ar atom concentration. Two V-I plots with the same slope can correspond to the low temperature and low pressure and to the high temperature and high pressure, but the Ar atom concentration is equal. Mainly, $p_{high}/T_{high}=p_{low}/T_{low}$, from witch T_{high} can be calculated.

The V-I curves, measured under 0,01 duty cycle were assumed to correspond to the room temperature. For these curves, the dependence of the V-I slope on the pressure was plotted. By interpolating of the plot the pressures (p_{high}), which correspond to the higher temperatures (higher duty cycles) were determined. At the end, the T_{high} values were calculated (see tables).

It was observed, that the gas temperature does not depend on the pressure in limits of accuracy of the measured data, so only the average temperature as function of duty cycle is presented in the tables. It is apparent from the Figs 4 and 5, that the power which is introduced into the plasma for the dc pulsed mode in the first 10 μs is one order of magnitude higher than for the rf pulsed mode at the end of the pulse. Hence the temperature values for the dc pulsed mode are higher than for the rf pulsed ones.

Duty Cycle **dc** pulsed	Temperature °C
0,01	20
0,02	36
0,05	55
0,1	74
0,2	116
0,5	149
dc f(U,p)	350

Duty Cycle **rf** pulsed	Temperature °C
0,01	20
0,02	19
0,05	20
0,1	25
0,2	33
0,25	44
rf	123

At this moment, the estimation of the dc discharge temperature is complicated, because the V-I curves are not linear due to the heating effect. It is questionable to select one slope of such curve. Therefore, the temperature for the dc mode in the table was given as dependent on voltage and pressure.

3. CONCLUSIONS

1. Shapes of current, voltage and emission intensity signals, obtained with two different pulse generators are compared. At research of the pulsed discharge, particularly of the afterglow it is very important to pay attention on the electronic circuit of the pulsed generator.

2. At the variation of voltage, pressure and duty cycle in the given range, the duty cycle has the main influence on the voltage current characteristics. The temperature of the plasma was estimated from these curves, but further investigation and comparison with model calculations are necessary.

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