Dr. Hermann Schlemm
Ion Beam- and Surface Technology
Saalbahnhofstraße 6
D-07743 JENA, Germany
Tel.: ++ 49 3641 22 73 29
Fax: ++ 49 3641 22 87 60
email: hermann.schlemm@jenion.de
http://www.jenion.de

JENION

Material Technology by New Plasma- and Ion Beam Techniques

Alternating Cold Cathode Plasma Sources

1 Application

The ACC-plasma sources from JENION generate at high vacuum a plasma with reactive gases for applications like:

- **Plasma Immersion Ion Implantation (PIII),**
- **Ion Assisted Deposition (IAD) of oxide and ceramic layers in conjunction with evaporators,**
- **Ion Beam Assisted Deposition (IBAD) of metals and semiconductors with ion energies from 20 to 200 eV,**
- **Diamond like carbon layer deposition (DLC),**
- **Surface modification with reactive plasmas.**

It's a cost effective solution for high vacuum plasma generation in circular and linear dimensions up to 600 mm length. Because these types of plasma sources generate a plasma with ions of an ion energy distribution between 20 and 200 eV often they are also called low energy ion sources [1,2].

Fig.1 shows the plasma source with its plasma output on the top. The sources can be mounted on a flange or better inline on an optimized position at the vacuum chamber. Fig.2 shows an nitrogen plasma from the output of a circular 80 mm – source and fig.3 shows an oxygen plasma from a linear plasma source (ACC 40 x 150 PS).


Fig. 1: Plasma source ACC-80 PS with filament neutralizer


Fig. 2: Plasma source ACC-80 PS in operation with nitrogen


Fig. 3: Linear plasma source ACC-40x150 PS in operation with oxygen (4x10^{-4} mbar, I_{plasma}= 0.25 A),

2 The Plasma Sources JENION ACC

2.1 Principle

Fig. 4 shows the principle of the patented [3] plasma source. Between three cathodes two further electrodes are arranged powered by a radio-frequency generator (50 kHz). It switches these electrodes between cathode and anode potential so that they act altering as cathodes or anodes at a cold cathode gas discharge. Because of the radio-frequency plasma generation isolating layers on the electrodes do not influence the discharge (like at dc-cold cathode discharges).

The plasma source delivers a powerful plasma stream to the vacuum chamber in dependence from the applied bias voltage. Optional a neutralizer (filament or plasma bridge neutralizer) can be used to keep the plasma potential of the plasma at the substrates at ground.

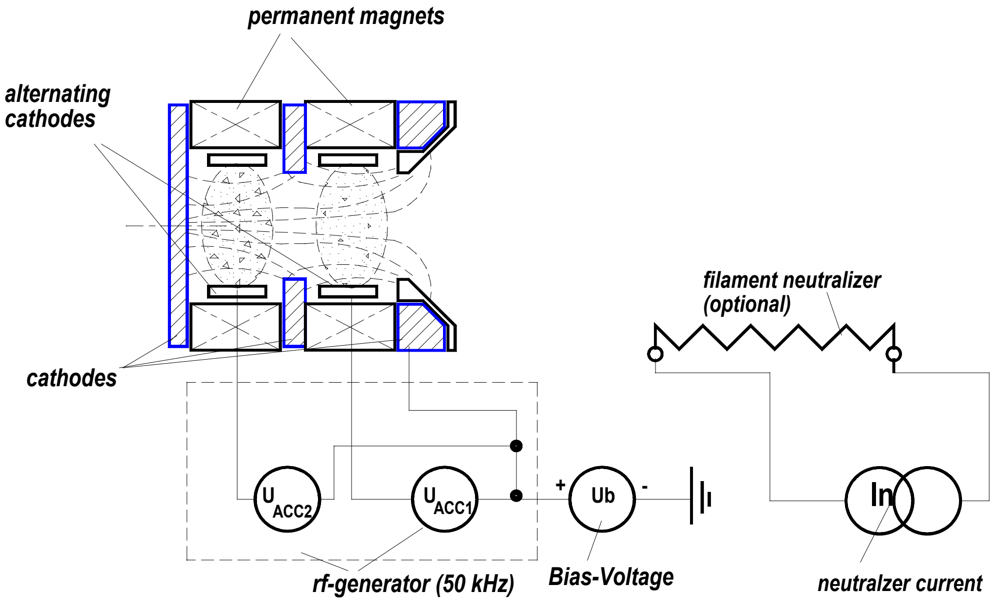

Fig. 4 Principle of the Alternating Cold Cathode plasma source

There are two different plasma regions at the vacuum chamber (Fig.5):

a) **near field plasma:** with high charge carrier concentrations 150 mm around the plasma source output and ion current densities between 0.1 and 1 mAcm^{-2},

b) **chamber plasma:** residual volume of the vacuum chamber filled with a nearly homogeneous weaker plasma and ion current densities between 10 and 50 µAcm^{-2}.

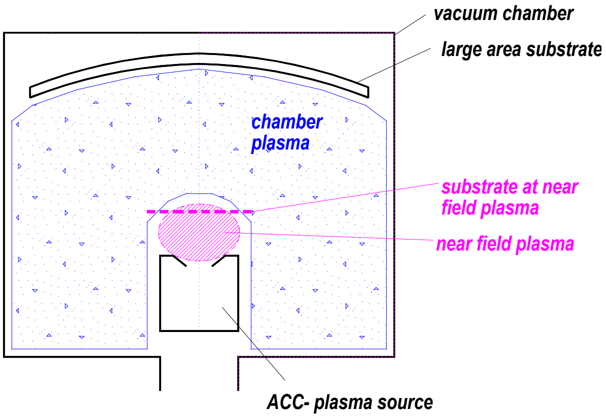

Fig. 5: Near field plasma and chamber plasma generated by an Alternating Cold Cathode plasma source

2.2. Technical Data

Tab.1 shows the technical data of circular ACC-plasma sources and Tab.2 shows the data of linear plasma sources. Most of this plasma sources operate also as ion source if completed with an extraction grid system (see [4,5]).

property	JENION ACC-40 PS	JENION ACC-80 PS
Plasma sources dimensions		
Plasma output dimensions	40 mm diameter	80 mm diameter
Vacuum flange	ISO 100 K, CF 100 or inline mounted	ISO 100 K, CF 100 or inline mounted
Output plasma current	10 – 100 mA	0.1 - 0.5 A
Discharge current	10 – 100 mA	0.1 - 0.5 A
Discharge voltage	350 - 800 V_s	350 - 800 V_s
Bias Voltage	0 V to 400 V	0 V to 400 V
ion current density near field plasma [mAcm^{-2}]	0.1 to 1	0.1 to 1
ion current density chamber plasma [µAcm^{-2}]	10 to 50	10 to 50
ion energy [eV]	20 – 200 eV	20 – 200 eV
impurities	0.05 to 1 % of the plasma current	0.05 to 1 % of the plasma current
neutralizer	Optional filament or plasma bridge	Optional filament or plasma bridge
gas flow [sccm]	5 - 30 (Ar)	10 - 100 (Ar)
water flow for cooling [l/min]	1 – 5 (only for long term operation)	1 – 5

Tab.1: Technical data of the circular plasma sources JENION ACC-40 PS and ACC-80 PS

property	ACC-40x150 PS	ACC-40x300 PS	ACC-40x600 PS
dimensions (length x width x height) [mm]	200 x 100 x 190	350 x 100 x 190	650 x 100 x 190
Plasma output width	60 mm	60 mm	60 mm
Plasma output length	150 mm	300 mm	600 mm
Homogeneous plasma length (at 100 mm distance, < 5%)	75 – 100 mm	200 – 250 mm	450 – 500 mm
vacuum flange	Inline mounted (optional ISO 250, CF 250)	Inline mounted	Inline mounted
ion energy [eV]	20 – 200 eV	20 – 200 eV	20 – 200 eV
ion current density near field plasma [mAcm^{-2}]	0.1 - 1.0	0.1 - 1.0	0.1 - 1.0
ion current density chamber plasma [µAcm^{-2}]	10 – 50 µAcm^{-2}	10 – 50 µAcm^{-2}	10 – 50 µAcm^{-2}
discharge voltage	500 – 900 V	500 – 900 V	500 – 900 V
discharge current	25 – 150 mA	50 – 300 mA	100 – 500 mA
Bias voltage	0 to 400 V	0 to 400 V	0 to 400 V
Neutralizer	Optional filament or plasma bridge	Optional filament or plasma bridge	Optional filament or plasma bridge
gas input	5 – 25 sccm	5 – 50 sccm	10 – 100 sccm
impurities (% of ion beam current density)	0.03 - 1	0.03 – 1	0.03 - 1
Cooling water flow	Optional (1-3 l/min)	1-3 l/min	2-5 l/min

Tab.2: Technical data of the linear plasma sources

2.2.1 Near field plasma technical data

The Figures 6 and 7 show typical data of the near field plasma. The plasma operates in a pressure range between 1×10^{-4} and 6×10^{-4} mbar (pumping speed 500 l/s, pumping speed dependence see chapter 4.2). Ion current densities up to 0.3 $mAcm^{-2}$ are reached. Fig.7 and 8 show the influence of the bias voltage and of the radio-frequency power (I_{ACC}) on the ion current density.

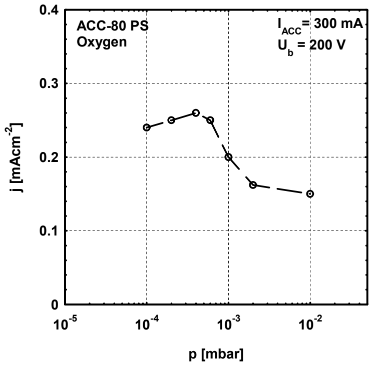

Fig. 6: Near field ion current density in dependence of the pressure

The ion current from the plasma source (plasma stream because of neutralization by plasma electrons) is accompanied by a significant flow of radicals.

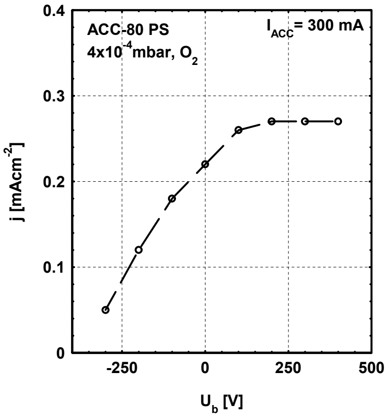

Fig. 7: Near field ion current density in dependence on the bias voltage

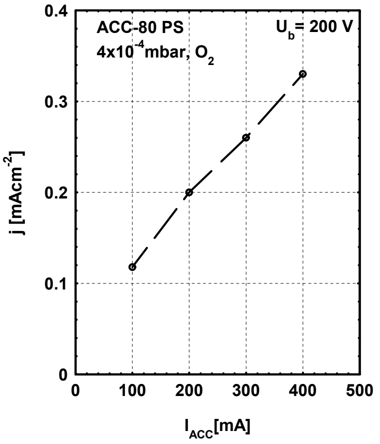

Fig.8: Near field ion current density in dependence on the discharge current

2.2.2 Chamber plasma technical data

The Figures 9 and 10 show typical data of the chamber plasma. The plasma operates in a pressure range between 1×10^{-4} and 6×10^{-4} mbar (pumping speed 500 l/s, pumping speed dependence see chapter 4.2). Ion current densities up to 30 μAcm^{-2} are reached. Fig.10 and 11 show the influence of the bias voltage and of the radio-frequency power (I_{ACC}) on the ion current.

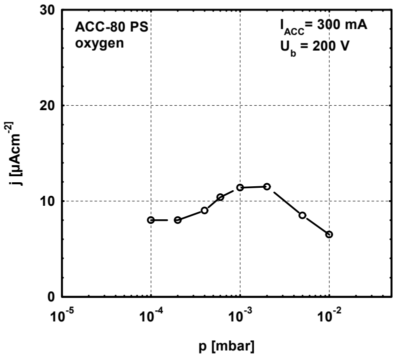

Fig. 9: Chamber plasma ion current density in dependence on the pressure

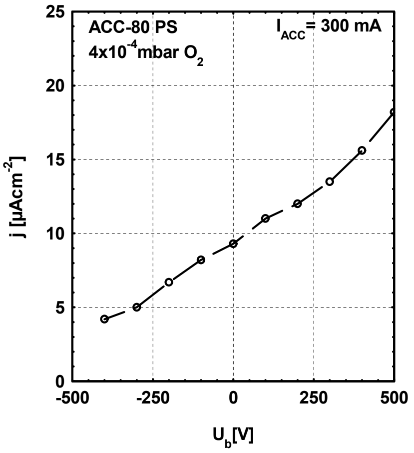

Fig. 10: Chamber plasma ion current density in dependence on the bias voltage

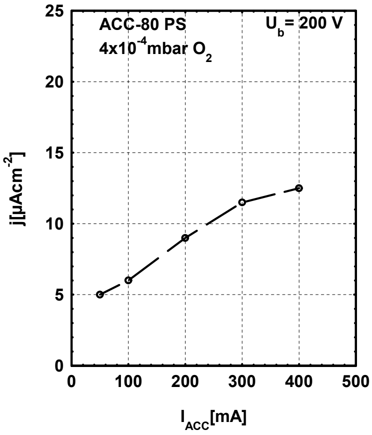

Fig.11: Chamber plasma ion current density in dependence on the discharge current

3 Components of the System

Fig.12 shows in an overview the installation of the plasma source. The plasma source system consists of the plasma source, which can be flange mounted or typical inline mounted at the vacuum chamber. The power supply consists of a special radio frequency power generator (40 – 50 kHz, rf-power depending on plasma source size) and of a dc-bias voltage supply. Optional a filament or plasma bridge neutralizer together with its power supply can be used. Optional a gas flow and vacuum control unit can be installed if not already part of the vacuum equipment.

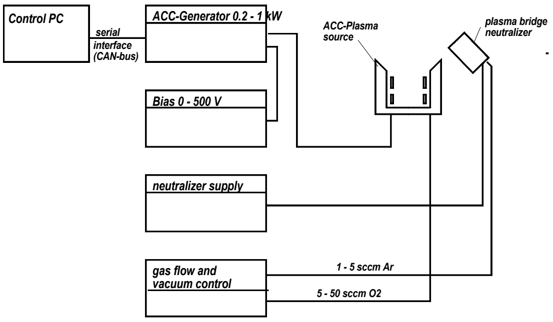

Fig.12: Overview of the plasma source installation

Because of the wide range of application of these plasma sources and of the different types of linear and circular sources nearly every installation is dependent on the customer.

4 Application Examples

Tab.3 gives an overview about the precursors usuable at the plasma sources. The main advantage of the plasma source is the total filamentless operation (no hot cathode), which enables the operation with oxygen. The oxygen plasma itself furthermore enables the periodically cleaning of the source from carbon and graphite layers resulting from a carbon containing plasma.
By this procedure a lot of molecular gases like hydrocarbons, fluorocarbons e.t.a. can be used.

Depending on the plasmachemistry caused by the used precursor (e.g. Cl_2) plasmachemical reactions between the electrodes and the plasma can lead to larger amounts of impurities, which can be lowered by use of more inert electrodes (see chapter 5, Modifications). The common used electrode material is stainless steel, working sufficient clean with most of the precursors of Tab.3. Electrodes made from graphite or titanium or some other materials can be produced.

Gas type	precursors
noble gases:	He, Ne, Ar, Kr
permanent gases.	H_2, N_2,O_2
hydrocarbons:	CH_4, C_2H_2, ... (graphite deposition at the ion source, removing by oxygen plasma)
fluorocarbons:	CF_4, C_2F_6,.... (graphite deposition at the ion source, removing by oxygen plasma)
chlorocarbons:	CCl_4, C_2CL_6,... (graphite deposition at the ion source, removing by oxygen plasma)
water, alcohol e.t.c.	H_20, C_2H_5OH,
halogens:	Cl_2, HCL

Tab. 3: Usuable precursors for the ACC-plasma sources

4.1 Nitrogen Plasma Immersion Ion Implantation (PIII)

Nitrogen plasma immersion ion implantation is a useful tool e.g. for creating hard surfaces at low temperatures of stainless steel machine tools. Nitrogen ions will be implanted by short (< 10µs) high voltage impulses from a plasma generated by an ACC-Plasma Source. The substrate temperature is controlled by the ion power heating rate (see Fig.13). At power rates of 1 Wcm^{-2} substrate temperatures of more than 250 C can be reached.

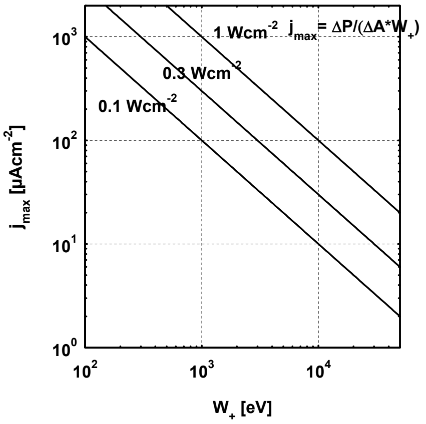

Fig. 13: Ion beam current density required for three different substrate heating power rates in dependence from the ion energy

Two different ion energy ranges for PIII with ACC-Plasma Sources are possible:

a) High energy implantation (10 - 50 keV): Because of the high ion energy ion current densities of some tens of µAcm^{-2} have to be implanted at the chamber plasma surrounding the substrate at large areas up to 1 m^2 (Fig.14).

b) Low energy implantation (100 - 1000 eV): Now the substrate should be surrounded by several ACC-Plasma Sources to implant the substrate at the generated near field plasma with ion current densities of typical 0.3 mAcm^{-3} (Fig.15).

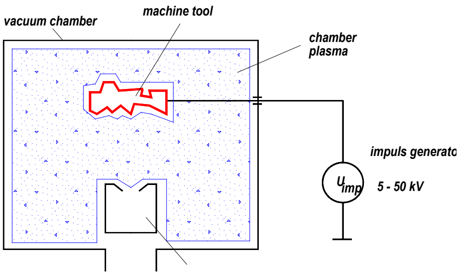

Fig.14: High energy PIII at the ACC-chamber plasma

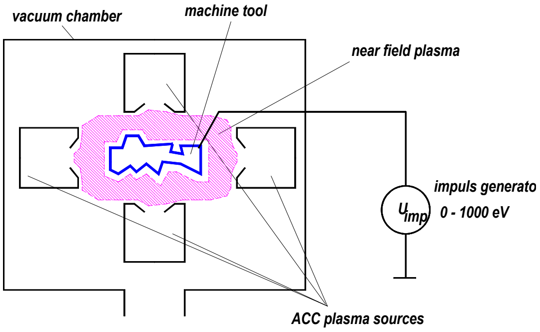

Fig.15: Low energy PIII at the near field plasma of several ACC-Plasma Sources

Electron beam evaporation requires vacuum chamber pressures below 10^{-4} mbar. On the other hand the plasma generation at the inner part of the ACC-Plasma Source is at $5x10^{-4}$ mbar and higher at its optimum. Fig.16 shows that with increasing vacuum chamber pumping speed (S_{Turbo}) the chamber pressure can be decreased down to $5x10^{-5}$ mbar at stable plasma generation.

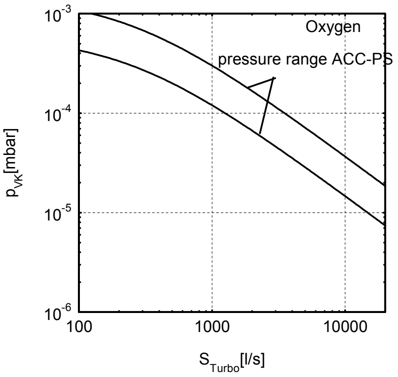

Fig. 16: Process pressure range (from min. pressure to max. pressure) for the plasma source ACC-80 PS in dependence of the pumping speed at the vacuum chamber.

4.2 Ion Assisted Oxide Deposition of optical and ceramic layers

Optical and ceramic oxide layers can be deposited by reactive or non-reactive magnetron sputtering of oxide targets or by evaporation of oxides or pure metals in conjunction with an oxygen plasma generated by an ACC-Plasma Source. The ion current and the oxygen radical stream (O_x) of the chamber plasma is large enough to enable oxide deposition at rates of 1 - 5 nm/s like common delivered from electron beam evaporators like shown at fig.17.

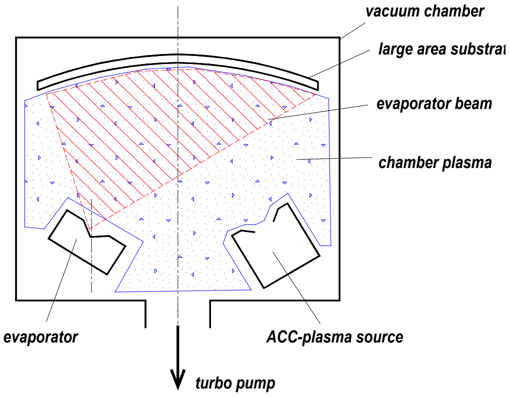

Fig.17 : IAD of oxide coatings in an oxygen chamber plasma

Because of the fact that oxide layers are isolating layers mostly deposited at optical substrates like glass the floating potential at these substrates can arise up to more than 100 V regarding to a deceleration of the ions coming from the plasma source. To keep the ion energy at sufficient high values these isolating substrates therefore have to be grounded by an additional electron density at the plasma generated by a neutralizer like filament neutralizers or plasma bridge neutralizers. Filament neutralizers have the principal problem to overcome 10 hours of operation at oxygen plasma. In this case plasma bridge neutralizers should be used.

5 Options and Modifications

Beside the ACC-plasma sources other ion-sources and components are available:

- Customer specified plasma output dimensions and inline arrangements,
- Pulsed plasmas,
- Plasma probe control of the ion beam current density and plasma probe curves [6],
- Customer specified arrangement of the plasma source at the vacuum chamber (inline, moved e.g. on a x-y stage),
- Linear broad beam ion sources for ion energies from 100 to 1000 eV [5],
- High energy broad beam ion implantation up to 50 keV (see " Broad Beam Ion Implantation with linear ACC ion sources JENION ACC-30x150 IMP, ACC-40 x300 IMP and ACC-40x600 IMP " [7]),
- Customer specified ion sources for broad ion beams for ion energies from 1 to 10 keV,
- Heated plasma- and ion sources for liquid precursors or low temperature melting metals like Pb, Zn e.t.c. [8].

6 References

[1] I.G. Brown, "The Physics and Technology of Ion Sources", J. Wiley & Sons, New York 1989.

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[6] “PlasmaMon – plasma probe measurement for plasma and ion beam analysis“, product information JENION 2002,

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