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Material Technology by New Plasma- and Ion Beam Techniques

Broad Beam Ion Implantation with linear ACC ion sources JENION ACC-30x150 IMP, ACC-40 x300 IMP and ACC-40x600 IMP

1 Application

Compact Broad Beam Ion Implanters basing on linear ACC-ion sources generate a high current ion beam with energies up to 60 keV for applications in the field of:

- **Ion implantation of medical implants,**
- **Surface modification by stoechiometric ion implantation to create oxide-, nitride-, or carbon layers,**
- **High current stoechiometric ion implantation for materials research,**
- **Textured modification of surfaces,**
- **Thin film micro alloy deposition**,
- **Surface preparation for bonding.**

It is a cost effective solution comparable to other PVD thin film processes for ion implantation with energies up to 60 keV for:

- **Bio-medical thin film preparation with excellent adhesion- and wear behaviour,**
- **Deposition of hard coatings on machine tools with excellent shape control of e.g. drills,**
- **Masked buried layer formation at microsystems in actuator- and sensor technologies.**

The Broad Beam Ion Implanter consists of a Linear Broad Beam Ion Source and of a substrate holder at high voltage. Depending on the broad ion beam cross section an ion beam current between 1 and 100 mA can be implanted, that means a cost effective high current implanter. The implanters are non mass separated in principal.

The ion energy range is from 1 to 60 keV with a corresponding implantation depth from 1 to 100 nm but because of the high implanted power density thermal stimulated diffusion processes lead to thicker thin films comparable to other thin film techniques

2 Linear Broad Beam Ion Implantation

Ion Implanters are well used in semiconductor fabrication. These are high specialised mass separated machines for ion doses in the range of 10^{10} to 10^{16} cm^{-2}. They generate ion beams with energies between 1 and 300 keV. The beams have typical diameters of 10 to 20 mm requiring a complex scanning mechanism to implant larger areas. Fig.1 shows the principle of such an implanter. The footprint of such a machine requires 10 to 20 m^2.

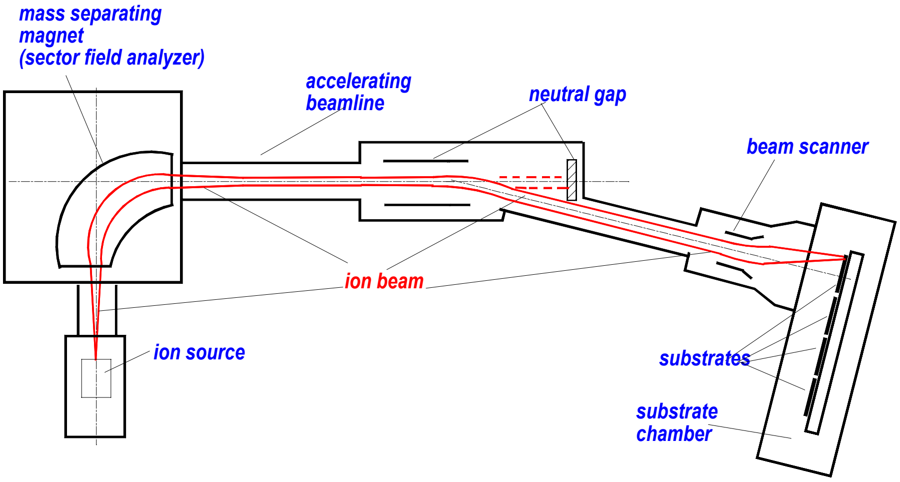


Fig.1:
Principle of a mass separated ion implanter used in semiconductor fabrication

In contrary to this Broad Ion Beam Ion Implantation can be arranged in a vacuum equipment not larger and not more expensive than at other thin film techniques. Fig.2 shows the simplest case of such an equipment. The broad ion beam delivered from a linear broad ion source (beam dimensions: width 30 mm length from 150 to 600 mm, see [7]) is accelerated by the substrate holder itself, which is at high voltage between 5 and 50 keV. At the rotating substrate holder a batch of substrates can be arranged and implanted in one procedure. Other substrate motions like linear transport e.t.c. also can be arranged.

A more complex Broad Ion Beam Implanter is shown at fig.3. Now a special Linear Broad Ion Beam Source is used generating an ion beam at high voltage potential up to 60 kV.

The ion beam is accelerated towards the substrates at ground potential. This enables, that there are not any restrictions for the substrate transport. Linear inline implantation, like shown at fig.3 can be carried out, heaters and other additional equipment can be installed for ion implantation.

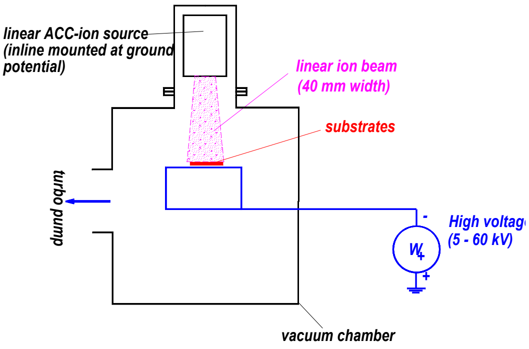
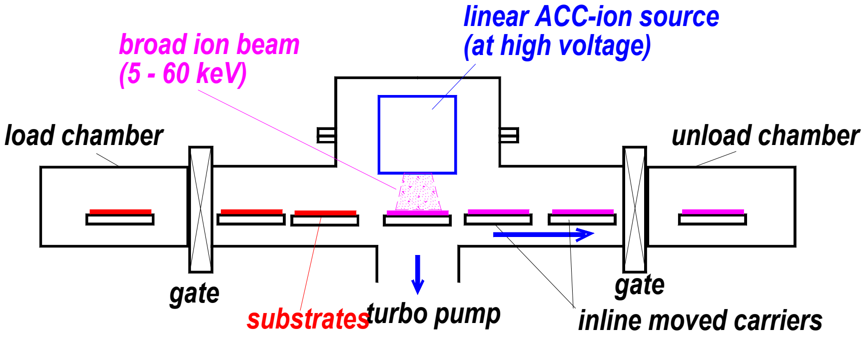


Fig.2: Schematic view of Broad Beam Ion Implanter with substrate holder at high voltage for batch processing



Tab.1. shows a comparison of the above sketched implantation concepts.

	batch implanter	linear inline implanter
high voltage is applied to	substrate holder	broad beam ion source
substrate motion	rotation (linear movement)	linear inline substrate transport
broad beam ion source	conventional linear broad beam ACC- ion source	special high voltage linear broad beam ion source
ion implantation processing	discontinues batch implantation with pump down times	continuos inline implantation
implantation technologies	single implantation technologies	implantation technology can be combined with other thin film technologies at the inline system
typical substrates	small dimension substrates suitable for batch processing with high prices	substrates up to 50 x 50 cm suitable for inline processing with prices comparable to other thin film technologies
cost of ownership and productivity	low cost of ownership, lower productivity	higher cost of ownership, high productivity

Tab.1: Comparison of batch- and inline Broad Beam Ion Implanters

2.1 Principle of high energy broad ion beams

Fig.4 shows the principle of the Alternating Cold Cathode Ion Source (for details see [7] and [6]).

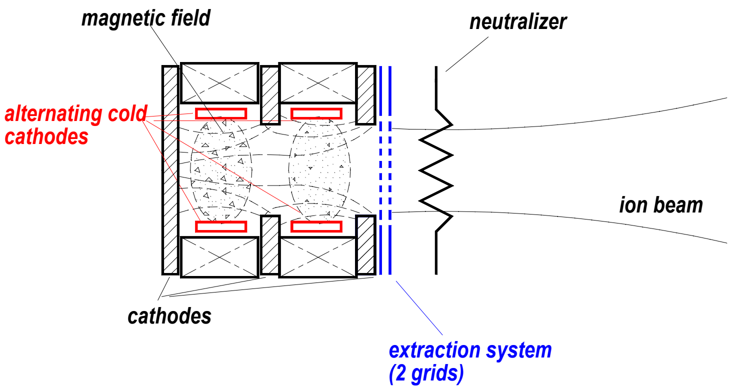


Fig .4: Principle of the Alternating Cold Cathode Ion source

At the discharge chamber a plasma is generated and ions are extracted by a conventional two grid extraction system.

The outcoming broad ion beam therefore has a typical ion energy from 500 – 1000 eV.

To generate a broad ion beam at energies up to 60 keV a second ion acceleration (postacceleration) is necessary [2,3,4]. This is only done by a potential difference between the ion source and the substrate. Like shown at tab.1 therefore exist two principal ways. To avoid backstreaming of secondary electrons generated by ion impact on the substrate a secondary electron suppression part on negative potential in respect to the substrates is arranged around the substrate.

2.2 Technical Data

The concept of ion implantation from Linear Ion Sources enables a wide range of implantation area.

Tab.2 shows the technical data and dimensions of Broad Beam Ion Implanters basing at this concept.

Property	ACC-30x150 IMP	ACC-40x300 IMP	ACC-40x600 IMP
ion source dimensions (length x width x hight) [mm]	200 x 100 x 190	350 x 100 x 190	650 x 100 x 190
Ion beam width (at 200 mm distance)	20 – 30 mm	30 -60 mm	30 - 60 mm
ion beam length (at 200 mm distance)	150 mm	300 mm	600 mm
homogeneous ion beam length (at 200 mm distance, < 5%)	75 – 100 mm	200 – 250 mm	450 – 500 mm
ion energy	5 – 60 keV	5 – 60 keV	5 – 60 keV
ion current density	5 – 50 µAcm^{-2}	5 – 50 µAcm^{-2}	5 – 50 µAcm^{-2}
ion beam	5 – 50 mA	10 – 100 mA	20 – 250 mA
discharge voltage	500 – 900 V	500 – 900 V	500 – 900 V
discharge current	25 – 150 mA	50 – 300 mA	100 – 500 mA
grid system	2 grid system from graphite (optional stainless steel, titanium, tungsten)	2 grid system from graphite (optional stainless steel, titanium, tungsten)	2 grid system from graphite (optional stainless steel, titanium, tungsten)
gas input	3 – 15 sccm	5 – 25 sccm	10 – 50 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 Broad Ion Beam Implanters

Fig.5 shows the implantation depth for the most used ions like N_2^+, O_2^+ or CH_x^+ and the according depth range. This is the range where ions stop after implantation without any further thermal induced diffusion.

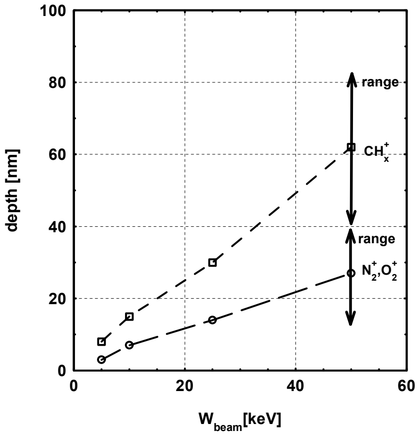


Fig. 5: Mean implantation depth in dependence from the ion energy and according depth range (at 50 keV). Depth calculations have been carried out by TRIM 2000 [8]

Fig.6 shows that stoechiometric ion doses between 10^{17} and 10^{18} cm^{-2} can be implanted in times from 10 to 60 minutes.

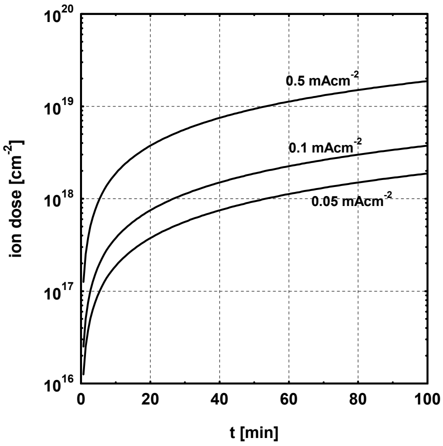


Fig. 6: Implantation dose in dependence from the implantation time (parameter ion current density of an atomic ion)

At this implantation times the ion beam heats the substrate to a steady state temperature in dependence of the electrical power density of the beam (see Fig.9), which is in the range of more than 1 Wcm^{-2}. This leads to a heating of the substrate in the range of 100 - 400 C, where diffusion of the implanted species can be much greater, resulting in very much broader implantation profiles than calculated in Fig.5.

3 Components of the System

A Broad Beam Ion Implanter following this concept consists of a vacuum equipment and of the ion beam part.

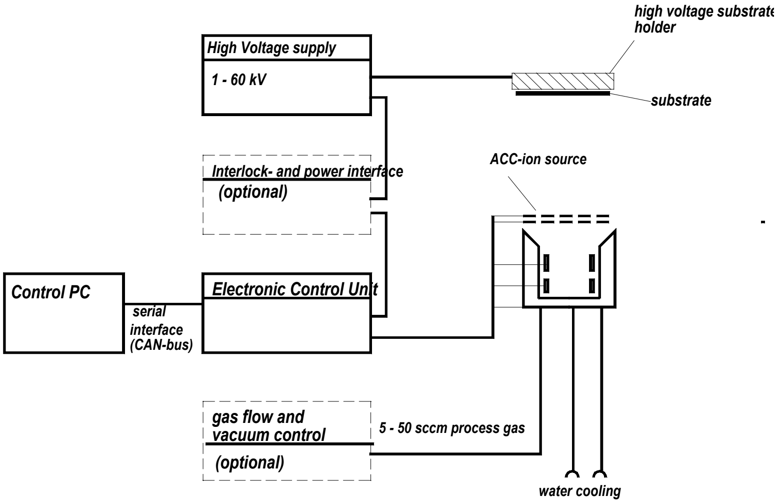


Fig.7: Overwiev of the Broad Ion Beam Implanter installation (substrate at high voltage corresponding to fig.2).

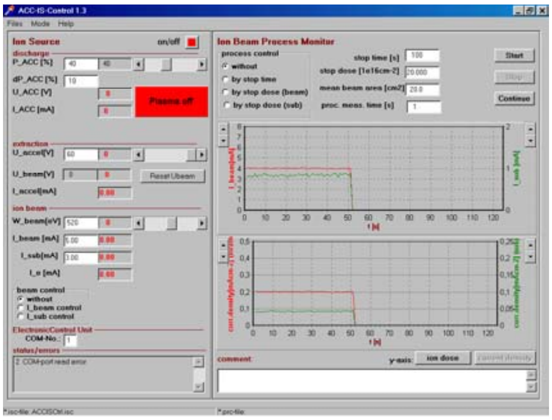
The implanter can be installed on an existing vacuum chamber but also complete solutions can be delivered. Fig.7 gives an overview about the installation and components for the implanter with substrate at high voltage.

3.1 Ion Source and Ion Beam Postacceleration

- Alternating Cold Cathode ion source (cold cathode ion source operating not with DC but with low frequency [7]),
- Usable for reactive gases (see Tab.3),
- Output ion energy of the broad beam ion source 500 - 1000 eV, ion current depending on ion source size (see tab.2),
- Impurities (sputtered metals from the cathodes) smaller than 0.1 - 1% ,
- High potential isolation of the substrate holder for high voltage up to 60 kV.

3.2 Electronics and Power Supplies

- Compact processor controlled ion source electronic control for grounded broad beam ion source (see [7]) or special high voltage ion source control,
- High voltage power supply for 0 to +60 kV (high voltage ion source) or 0 to –60 kV (high voltage substrate holder),
- Computer control by serial interface,
- Optional interlock control unit (if not already realized by the vacuum equipment control).



P_ACC [%] 40 40
dP_ACC [%] 10
U_ACC [V] 0
I_ACC [mA] 0
Plasma off
U_accel[V] 60 0
U_beam[V] 0 0
I_accel[mA] 0.00
W_beam[eV] 520 0
I_beam [mA] 5.00 0.00
I_sub[mA] 3.00 0.00
I_e [mA] 0.00
beam control: ● without ○ I_beam control ○ I_sub control
ElectronicControl Unit COM-No.: 1
status/errors: 2: COM-port read error
process control: ● without ○ by stop time ○ by stop dose (beam) ○ by stop dose (sub)
stop time [s] 100
stop dose [1e16cm-2] 20.000
mean beam area [cm2] 20.0
proc. meas. time [s] 1
comment:
y-axis: ion dose
*isc-file: ACCISCtrl.isc
*pro-file:

Fig. 8: Screenshot of the ion source control software for ACC-ion sources

3.3 Optional Components

- Stepper motor driven substrate handling mechanisms,
- Interlock unit for safe ion implanter operation,
- Ion beam profile analyzer with an integrated line of faraday cups [9],
- Mass selected ion implantation by using the mass separated ion source JENION K-40 MIS [6] (this is a filament ion source which does not operate with oxygen and some other reactive gases)

3.4 Software

Fig.8 shows the software controlling the implanter operation but not any part of the vacuum equipment. The software operating under

WIN9x, WIN/NT, WIN2000 and WIN/XP controls all functions of the broad ion beam implanter like:

- Ion source discharge (ACC-discharge, plasma ignition),
- Ion beam extraction (ion energy, extraction voltages for screen- and acceleratorgrid),
- Ion beam data (ion energy, total ion beam from the ion source, ion beam at the substrate, ion beam from the filament neutralizer (optional).
- Ion beam regulation (regulation of the total ion beam or the substrate ion beam to a setpoint value).

The integrated ”ion beam process monitor” can be used for analyzing the generated ion beam or for process control by:

- Observing ion beam current, ion beam dose or ion beam density over a given process time,
- Process stopping after a programmed time, or after a programmed ion dose.

All parameters for operation of the system are loaded and saved by files ("settings"). All results of the ion beam process monitor can be saved as ASCII-files for further documentation. The software contains an extended integrated help system. Additional a manual is delivered, describing the system, its theory and function and some application examples from all kinds of applications:

- Ion source operation (ignition and operation of the discharge, extracted ion beam),
- Postacceleration (ion energy, ion current, secondary electron suppression),
- Ion beam (ion energy, ion beam control).

4 Application Examples

The Broad Beam Ion Implanter is thought to be a non mass separated implanter for the ions:

- nitrogen: formation of nitride layers,
- oxygen : formation of oxygen layers,
- carbon: formation of carbide layers,
- and noble gases.

Furthermore tab.3 shows hydrogen and chlorine, which also successful can be implanted. Some more precursors are useful.

Precursor	Ions	main ion	mean ion energy of the implanted atomic ion	mean dose factor	Remarks
H_2	H^+(w), $H_2{}^+$(s),$H_3{}^+$(s)	$H_2{}^+$	0.5 *W_{beam}	2	$H_3{}^+$-formation pressure dependent,
D_2	D^+(w), $D_2{}^+$(s),$D_3{}^+$(s)	$D_2{}^+$	0.5 *W_{beam}	2	$D_3{}^+$-formation pressure dependent
N_2	N^+(m), $N_2{}^+$(s),	$N_2{}^+$	0.5 *W_{beam}	2	$N_2{}^+$dissociates up ≈1 keV, nitride formation
O_2	O^+(m),$O_2{}^+$(s),	$O_2{}^+$	0.5 *W_{beam}	2	$O_2{}^+$dissociates up ≈1 keV, oxide formation
Ar	Ar^{2+}(w), Ar^+(s),	Ar^+	W_{beam}	1	for controlled ion energy deposition
C_2H_2	C^+(m),$CH_x{}^+$ (s), $C_2H_x{}^+$(w)	$CH_x{}^+$	≈0.8*W_{beam}	1.3	$CH_x{}^+$ dissociates up ≈1 keV, carbide formation,
Cl_2	Cl^+(m),$Cl_2{}^+$(s)	$Cl_2{}^+$	0.5 *W_{beam}	2	$Cl_2{}^+$dissociates up ≈1 keV, chloride formation

Tab.3: Overview of some ion source precursors, their ion source dissociation products (intensities of the peaks in brackets: s - strong, m - middle, w - weak, ns - non separable), and of the

The concept for implanting non mass separated ions is, that at ion energies greater than 1 keV nearly all molecular ions dissociate when impacting the surface and penetrating the solid body as atomic ions with a mass dependent part of the energy of the molecular parent ion. The column "mean ion energy of the implanted atomic ion" at Tab.3 shows typical ion energies of these atomic fragments.

The ion dose calculated by ion beam integration can be multiplied by the "mean dose factor" (which is mostly 2) to get the atomic ion dose. According to Fig.6 this gives half times shorter implantation times.

Fig. 9 shows the implanted power density (P) in dependence from the ion energy (W_{beam}) and the ion current density (j). At typical implantation parameters (40 keV, 0.1 $mAcm^{-2}$) the substrate is heated with nearly 4 Wcm^{-2}. Fig.9 shows that there is a temperature caused limitation regarding the implantation parameters at high current broad ion beam implanters.

$$P = \frac{W_{beam}}{e} * j$$

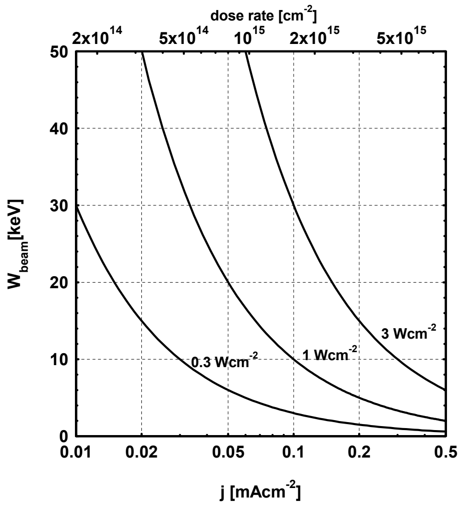


Fig. 9: Implanted power density in dependence from the implantation parameters

4.1 O_2^+ - implantation for glass bonding

The today's microsystem technique requires bonding of different components made from different materials at one chip. Beside other techniques bonding (like wafer bonding) could be a solution. Fig.10 shows two oxygen implanted glass plates (20 keV, $5x10^{16}cm^{-2}$ O_2^+) with their strong increased adhesion.

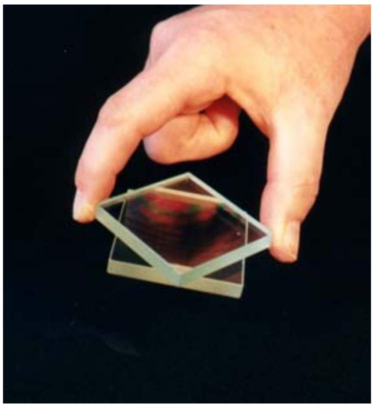


Fig.10: Demonstration of the adhesion of two oxygen implanted glass plates

4.2 N_2^+ -implantation in stainless steel

The most advantage of ion implantation in hard coating production is that ion implantation leaves the dimensions of the implanted tools completely unaltered. Therefore the hardening by implantation of small drills and other machine tools is successful, if the dimension of the cutting edge is so small, that surrounding PVD-layers would substantially decrease the sharpness. Fig.11 shows as an example the increase in wear protection by ion implantation dose for tungsten carbide drills.

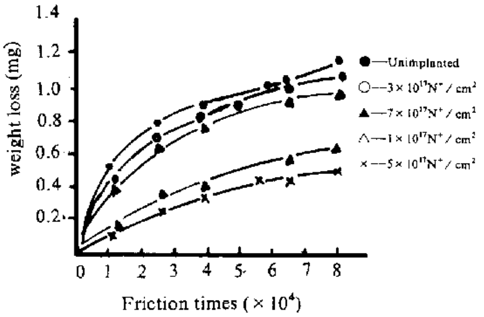


Fig.11: Increase in wear protection by ion implantation for tungsten carbide tools.

5 Options and Modifikations

Broad ion beam implanters are in every case unique vacuum equipments made for a special application. Like shown at tab.1 two principal solutions exist. Moreover for every implanter a detailed discussion to find the best implanter solution should be started. These could be:

- Other ion beam dimensions, in connection with the substrate dimensions (e.g. implantation of tubes, wires e.t.c.),
- Complete equipment solutions in cooperation with an equipment supplier,
- Customer specified ion beam solutions of beam positioning respectively to the substrate to implant only the regions required by the technology,
- Broad beam mass separated ion implantation with an ion source JENION K-40 MIS ([5]).

6 References

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