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Indigenous Ion Sources for Material Processing

R. Bhattacharyya

National Physical Laboratory, New Delhi-110 012
E-mail: raghubhatin @yahoo.com

ABSTRACT

Ion beam sources for material processing in their working are no different from those required for space thrusters, ion implanters or for fusion experiments. They are scaled down versions of the devices earlier developed for space research. However, they are not being manufactured in the country. Their use in ophthalmic coatings and DLC for magnetic heads, CD, etc. are commercially attractive. In this technical report is suggested as to a strategy how to develop them, pooling resources from different active groups in the country, with specific targets. Dc gridded,Rf gridded, Saddle field, End Hall and ICP sources have been identified based on preliminary work carried out at different places in the country. This areas may be read more as a research opportunity report.

Keywords: Material science, ion source, ion beam sources, material procesing, space thrusters, ion implanters, ion implantation

1. INTRODUCTION

Ion Source is a device that produces a stream of ions, especially for use in particle accelerators, an ion implantation equipment, or for producing and/or tailoring the properties of a thin solid film.

Ion beams in MeV and keV ranges are routinely used for condensed matter research, heavy ion fusion experiments, as also in VLSI manufacturing (ion implantation) and are well documented in scientific literature. Using same very principles, devices developed that assist in tailoring the material properties of thin films being grown inside a vacuum system have also become very important for ophthalmic industry in general and for magnetic heads in particular (for coating diamond like carbon (DLC) films). Apart from these applications, creating significant business opportunities, when it comes to use of polymeric substrates, prohibiting any significant substrate heating, their use is indicated to help the adatoms the required mobility to settle into the optimum position in the growing film, for example during coating of TCO films on polymeric substrates, for use in various organic/polymeric electronic devices like OLED. A large variety of Ion beams have been devised till date and also a large choice of such devices is commercially available for diverse applications. We refer to them as we go along. In the Table 1 some of the ion sources specifically suited for Accelerator Application is reproduced from a very good article on the subject recommended for all readers to gain a fundamental understanding of ion sources[1].

Again, modern ion thrusters use inert gases for propellant for space-borne vehicles, to eliminate all risks of the explosions associated with chemical propulsion. These thrusters use some inert has like xenon, which is chemically inert, colorless, odorless, and tasteless. It is to be observed that only relatively small amounts of ions are ejected, but they are traveling at very high speeds. For the Deep Space 1 NSTAR ion thruster probe, of NASA ions were shot out at 146,000 km/h. Newton's Third Law of motion states that for every action there is always an equal and opposite reaction. A good and appropriate example is the air escaping from the end of a balloon and propelling it forward. Conventional chemical rockets burn a fuel with an oxidiser to make a gas propellant. Large amounts of the gas push out at relatively low speeds to propel the spacecraft.
The generated thrust in an ion thruster T depends upon on the ion current, I beam and Energy V_{beam} according to

$$T = m_i/e.\ I_{beam}\ (2eV_{beam}/mi)^{1/2}\ \gamma'_{tot}$$

where γ'_{tot} is a correction factor that includes the effect of beam divergence and multi-charged ions[3]. Where other symbols have their usual meaning.

One is, again, aware of the need to accelerate particles like proton, $H(-)$ ions, electrons and host of heavier ions for diverse technological and research applications. To obtain different species of ions, again there exists preferred techniques. Electrons are easily emitted by heated cathode and that lead to the evolution of Vacuum tube electronics and CRT displays. Similarly, field emission of electron is also possible with CNTs now. Protons need Duoplasmatrons, and H(-)ions magnetron/ Penning sources. For most heavy ions, ECR (Electron Synchrotron Resonance) is the preferred ion source, both for high and low energy applications. (A brief technical report of the work in this area at BARC is given in their News letter No 259). Specifically a beginning

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Table 1. Ion sources specifically suited for accelerator application[1].

- Bayard-Alpert type ion source
- Electron Bombardment ion source
- Hollow Cathode ion source
- Reflex Discharge Multicusp source
- Cold & Hot –Cathode PIG
- Electron Cyclotron Resonance ion source (ECR)
- Electron Beam Ion Source (EBIS)
- Surface Contact ion source
- Cryogenic Anode ion source
- Metal Vapor Vacuum Arc ion source (MEVVA)
- Sputtering type negative ion source
- Plasma Surface Conversion negative ion source
- Electron Heated Vaporization ion source
- Hallow Cathode ion Ardenne ion source
- Forrester Porus Plate ion source
- Multipole confinement ion source
- EHD-driven liquid ion source
- Surface ionization ion source
- Charge exchange ion source
- Inverse magnetron ion source
- Microwave ion source
- XUV-driven ion source
- Arc plasma ion source
- Capillary arc ion source
- Von ardenne ion source
- Capillaritron ion source
- Canal Ray ion source
- Pulsed spark ion source
- Field emission ion source
- Atomic beam ion source
- Field ionization ion source
- Arc discharge ion source
- Multifilament ion source
- RF plasma ion source
- Freeman ion source
- Liquid metal ion source
- Beam plasma ion source
- Magnetron ion source
- Nier ion source
- Bernas ion source
- Nielsen ion source
- Wilson ion source
- Recoil ion source
- Zinn ion source
- Duoplasmatron
- Duapigatron
- Laser ion source
- Penning ion source
- Monocusp ion source
- Bucket ion source
- Metal ion source
- Multicusp ion source
- Kaufman ion source
- Flashover ion source
- Calutron ion source
- CHORDIS

has been made by designing and developing a high current duoplasmatron ion source followed by a compact, microwave cathode plasma source. The experience, thus gained, is being utilised to develop an ECR source which will deliver 50 mA of proton beams at a voltage of 50 kV. It appears APPD, BARC, has established a good base in this technology which can be profitably utilised for the development of more modest sources for thin film-related work.

Ion sources are also needed for isotope separation and spectroscopy.

Figure 4 shows an ion source used in ion implantation (Coultron model G-2).

The author succinctly summarizes in the Table 2, the confluence of interest in the development of ion sources for such diverse and important application and their chronological development at a place of international repute, university of GieBen. Radio frequency ion beam source families of the University of GieBen (Reproduced from published literature[6]).

1. Number means ionizer diameter (cm)
2. Rectangular
3. Hexagonal
4. Kr, Ar, O_2, N_2, CO_2, $CBrF_3$, C_4Hs, SF_6, CF_2Cl_2
5. Full beam extraction not possible at GieBen

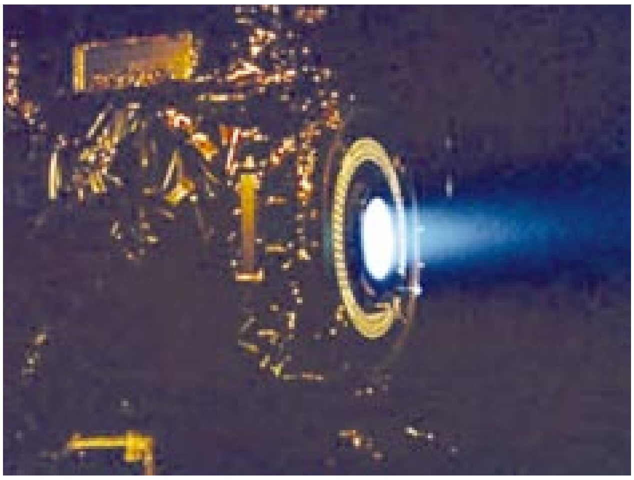


Figure 1. Xenon ion discharge from the NSTAR ion thruster for deep space probe.

Figure 2. An end hall source.

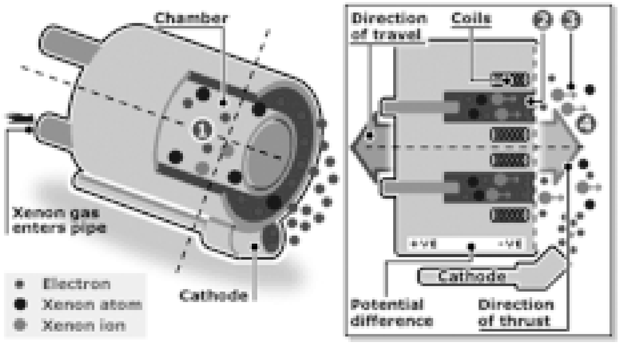


Figure 3. Schematic of an end hall source credit NASA, www.nasa.gov.

Figure 4. Ion source used in ion implantation (coultron model G-2).

This confluence of interest is to be noted to plan a cluster approach to the development of such ion sources indigenously, involving laboratories working in the areas of aerospace, nuclear accelerators, Plasma and thin film technologies.

Some important initiatives have since taken place, in developing higher energy systems (and sometimes the devices as well) at the cyclotron center BARC in Kolkatta, and in places like IUAC, BARC-Mumbai, SINP, CAT ,IPR, NPL, IISC. However, reliable commercial ion source devices for thin film applications of indigenous origin are not presently available in the country. A very modest DC operated device is available for laboratory use from M/s TAS, New Delhi. Based on some in house research efforts undertaken at the National Physical laboratory and elsewhere in the country, over last many decades, in the present review, a strategy has been suggested. We have in many ways succeeded in recent years to develop and manufacture our own Vacuum & thin film related equipment and Industry leader M/s Hind High Vacuum Company also in recent years become very sophisticated and also succeeded in exporting to technologically advanced countries. However, this is one area which remains neglected.

Intertwined with Ion source development is the development of the related Power sources DC, RF, MW. Sadly again, other than most elementary applications such power supplies are not again available meeting the stringent requirement of ion sources. Ion sources may as well be viewed as compact plasma reactors, sputtering, PECVD, vacuum plasma arc, etc types . In fact ,the related subjects like gaseous electronics, vacuum tubes (specially microwaves), ion optics have been studied for very long in this country in isolation .

First, the authors have taken only those devices which need dc power supplies. And highlighted the work at NPL on Saddle field ion sources, that though operated using only dc supplies, have the attribute of a RF discharge, thus charging of the substrates during coating does not

Table 2. Summary of the confluence of interest in the development of ion sources for diverse and important application and their chronological development

		Working	Rf power	Ion current	Beam voltage	Research, development and qualification programs
Thrusters for space propulsion	RIT -4^{-1}	*Hg*	20	0.03	2	1968-1977
	RIT-10	*Hg. Xe*	85	0.13	1.5	since-1960
	RIT-15	*Hg, Xe, Ar*	150	0.25	1.5	1974-76, since 1982
	RIT-20	*Hg*	200	0.5	2.4	1971-1975
	RIT-35	*Hg, Xe, Ar*	900	2.5	0.5…2.5	1972-80, since 1983
Injectors for fusion machines	RIG-10	H_2	$4.5x10^3$	10^5	30	1977-1985
	RIG-15	H_2	1×10^3	2^5	30	1982-1986
	RIG-20	H_2	20×10^3	18^5	40	since-1982
	RIG- 10 x 20^2	H_2	10×10^3	13^5	30	1982-1985
	RIG-10 x 30^2	H_2	1.5×10^3	4^5	25	1983-1986
	RIG-25 x 50^3	H_2	$< 120 \times 10^3$	80^5	80	since-1986
Sources for material processing	RIT – TEX-8	*Xe*	70	0.001	2.5	Since 1978
	RIG – 10 G	*He,Ne,Ar,*O_2,	500	0.08	5	1981-1985
	RIT – 10 LP 5	N_2CO,CO_2	300	0.3	1.5	since 1985
	RIM - 10	*Different* O_2, N_2, *Ar*	300	0.3	0.2….3.5	since-1986

pose a problem. The authors then moved on to RF ion sources and emphasise that unless an auto matching circuit is developed, not only they fail to develop such sources, they also do not succeed in developing (Inductively Coupled Plasma) ICP-based Deep Reactive Ion Etchers (DRIE) required for MEMS work in the country. Though microwave-based PECVD reactors as also ECR etchers have been developed at NPL-CEERI and elsewhere, compact ECR ion sources have not yet been developed. The case of ion sources with thermionic emitters are then taken up ,the representative and most successful device being advance plasma source (APS) of M/s Leybold that has revolutionised thin film device manufacture in no uncertain manner.

Scope of the present review paper, therefore, remains limited being essentially confined to presenting a technical report from where the authors have arrived and where they need to go, say, in next 3-5 years time. In that sense it may be read as a research opportunity report. The titles of a couple of books on the subject[17,18] and a short bibliography at the end is appended for discerning readers who wish to make a serious effort to understand the intricacies of the design and working of such devises.

The schematic, (Fig. 5), (Anders, Fig. 1)[2] reveals what is at the interface of convergence of plasma reactor development and the ion sources development ,which sadly we have so far neglected in this country. One will notice easily that how we extract ions and neutralise them with electrons that needs focused attention. In the schematic above a system of grids is shown and one needs to have an intimate knowledge of modelling soft-wares with codes, ion optics, and simulation techniques to develop ion sources that meet industry standards. However, as we will shortly see for material processing applications, in many cases, use of grids can be dispensed with these are the structures that are placed higher in priority in our plan to succeed in this area in the near future.

For sources required for the material processing applications, in energies in tens to about 1.5 KeV, most often a glow discharge needs to be maintained in some part of the source.

Based upon how the gaseous plasma is generated and sustained and how the ions are extracted and neutralised one can group together the large number of ion sources mentioned at the beginning of this article in the following three categories, based solely on the electric power supply used.

Direct current (dc) operated ion sources: in this category fall, Kaufman source, dc gridded sources, Hollow Cathode sources, Saddle field sources, Arc ion sources, End hall souses

Rf ion sources: Including ICP sources.

VHF and Microwave ion sources: including ECR sources.

The phenomenon of Discharge of electricity through rarefied gases becomes dominant in this initial ion generation process. This will be very briefly discussed now.

As shown in the Figs. 6 and 7 when one applies a moderately high voltage to a vacuum vessel with a pair of electrodes small, typically of the order of nA current is first produced by background ionization. When the voltage is raised significantly the current is found to grow exponentially, of the order of many µA due to Townsend multiplication and the onset of corona. Further increasing the voltage, all of a sudden the gas under study starts to glow and it is possible to have many mA of current at a much reduced voltage. The glow discharge is maintained and amplified by secondary electrons emitted by the cathode. That is one reason that dc discharges are not often recommended for many ion source application, unless a thermionic source is also incorporated .It should be emphasized most discharge based ion sources operate at the low current end of glow discharges

Sputter deposition, and therefore, sputter ion guns operate at the abnormal discharge regime, Vacuum ion Arc ion sources at the low voltage high current regime of the

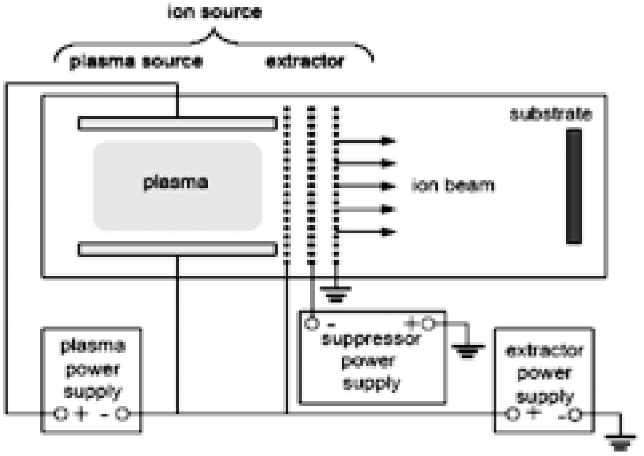


Figure 5. The schematic reveals of what is at the interface of convergence of plasma reactor development (anders, Fig. 1 Ref. 2).

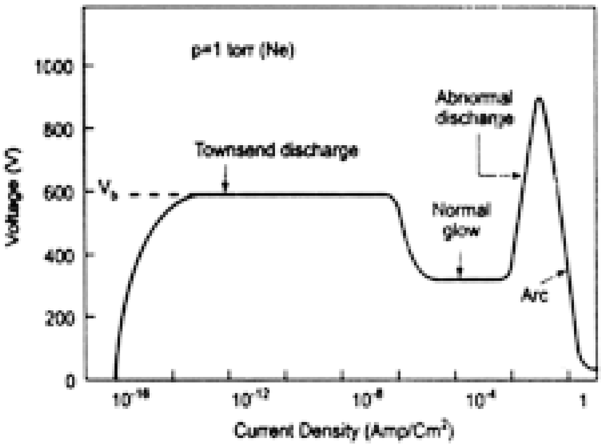


Figure 6. Shows that with the raise in voltage significantly the current grows exponentially, of the order of many µA due to Townsend multiplication and the onset of corona.

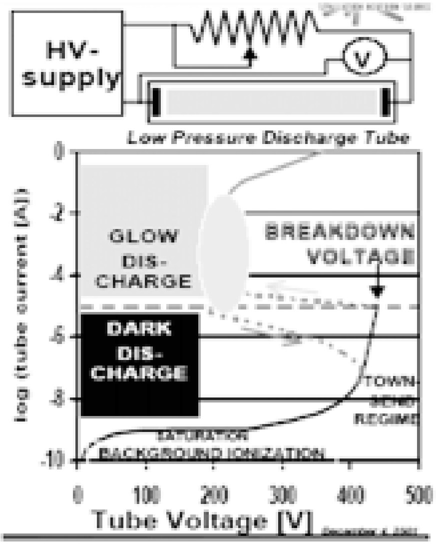


Figure 7. The glow discharge is maintained and amplified by secondary electrons.

curve whereas most other ion sources operate in and after the onset of Townsend glow discharge. It is to be noted in our lab and elsewhere we operate various reactors for thin film deposition the same way. The experience gained in working with plasma reactors one can, therefore, be easily translated in the understanding and fabrication of the desired ion sources.

The voltage at which a low pressure gas breaksdown depends only on the ratio of the electrode gap d and the mean free path for ionization ëi, or p•d, the product of gap *d* and the pressure *p*. No breakdown occurs at very low pressure and at very high pressure. Therefore, one normally starts a discharge ion source by first applying the arc voltage (as shown in Fig. 6) and then slowly increasing the gas pressure until visible plasma develops. The minimum voltage required to sustain a discharge (a glow discharge, as shown in Fig. 7) and corresponding p•d depend on the composition of the gas and secondary electron emission coefficient of the cathode material in question. A plasma is composed of neutrals, electrons and ions with densities n_n, n_e and n_i, typically in the range between 10^{10}–10^{16} particles per cm^3corresponding to a pressure between 10^{-6} and 0.1Torr. The repulsive nature of equal charges requires that essentially all plasmas are practically neutral (quasi-neutral). Plasma physics dominates if degree of ionisation $n_i/(n_i+n_n)>0.1$. Generally, the ion beams in these applications when compared to the conventional plasma intensive techniques, i.e., different types of plasma sputtering/etching, PECVD methods and devices, offer a number of distinct advantages. Like independent control of ion energy and ion current density, finite ion energy distribution width; well-defined charge state and beam direction; space separation of ion generation and appliance zone The extraction/acceleration system of the most popular modification of such ion sources comprises two or more multi aperture grids. This modification, applied mainly in sputtering and etching, is capable to produce low-divergent beams with high-ion current densities only at high-ion energies. It has been proved recently that thin films grown by ion assisted physical vapour deposition have better properties when using low-energy ion bombardment at high ion densities.

A large number of review articles and books are now available the subject. In the following a Kaufman ion source is schematically shown (Fig. 8). H.R.Kaufman's contributions, right from ion sources for space-borne vehicles to the present commercial ion source, R & D for material processing is acknowledged by all and M/s Kaufman & Robinson remain the resource centre and technology providers to many well established manufacturers world wide.

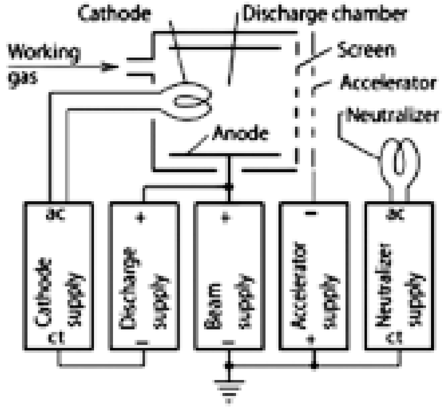


Figure 8. A schematic of the Kaufmain's ion source.

Another important class of ion sources which are mostly to be seen with the laboratories in this country is dc gridded Ion source and is shown schematically in the Fig. 9.

It is be noted that such a source has no thermionic emitter to generate a gaseous plasma, a thermionic filament or a metal tip. Because there is no thermionic emitter it can very well work with oxygen and other reactive gases.

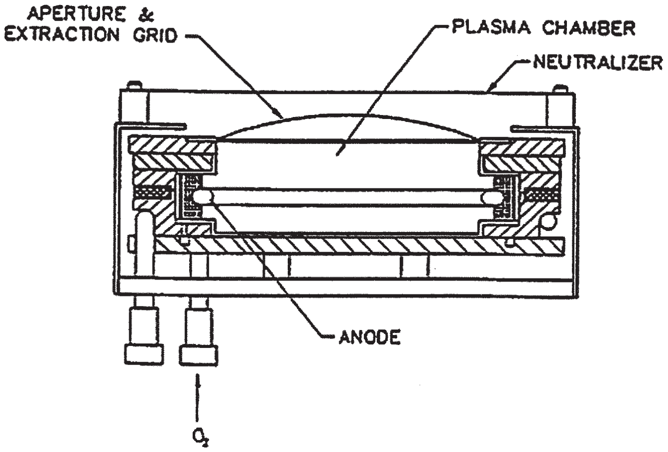


Figure 9. Using dc sources and a hollow cathode structure, a different type of cold cathode ion source has been developed by M/S Anatech

The emitter region of the source generates a plasma discharge with a cold cathode in side a hollow cathode (hollow cathode source description follows). An electron rich plasma is generated in the emitter streams to the anode as a result of the pressure differential between these two zones. A magnet near the emitter orifice bends the plasma stream into the B field of the permanent magnets in the anode. The plasma swirls in the anode to achieve uniformity, and applied anode voltage imparts the desired energy to the ions. Charge exchange between electrons and ions in the anode also produces a high percentage of energetic neutrals. The grids serve both as a gas baffle to create a second pressure zone in the anode and a means of electrical extraction to the process chamber. High extraction energies are not required, as the plasma extracts from the anode to the process chamber by the pressure differential between these two zones. The source requires gas flows from 3 to15 sccm to sustain the plasma between pressure zones within the source, which operates between 8 x 10^{-5} Torr and 3 x 10^{-3} Torr in the chamber depending upon the pumping capacity of the vacuum system for that particular operating gas. Beam current varies according to the pumping speed and the capacitance of the vacuum system. Typical beam current is a few milliamp at low pumping speeds in Argon and up to 50 milliamps at high pumping speeds in Oxygen. The ion sources are available with convergent, divergent and collimated grids. Molybdenum grids are recommended, and graphite grids are optional. Collimated grids produce a beam with a five to a ten degree half angle at high energy, and ten to twenty degrees at low energy. Divergent grids produce a beam with a fifteen to a twenty degree half angle. Convergent grids focus seventy five percent of total beam current in a spot size half of nominal beam diameter at the face of the optics at twenty centimeters distances from the grids. (Information adapted from Anatech brochure[19])

Dc gridded cold cathode devices are being marketed by many manufacturers round the world like Denton, Commonwealth Veeco, Atom Tech, and others. The above description is of a typical such generic cold cathode device and should not be taken as author's preference or recommendation.

We now only pick and choose a few such devices which has relevance to our stated need, that is to be able to develop on our own those sources which are not complicated and can easily be assembled .Bottom line is the use of permanent magnets, heaters and grid structures may be avoided as for as possible. It may be noted the earliest successful such device, a Kaufman source, had all these .Recent developments have shown very encouraging results as one is able to dispense with a few of the above stated restrictions.

We reproduce in the following some important considerations relating to ion sources from a very important and exhaustive publication in this field by Andre Anders Paper LBNL-57127[2]

- The terms *low-density* and *high-density* plasma are often mentioned. It is common to consider plasma densities of 10^9-10^{10}cm^3 as *low*, while *high* density implies10^{10}-10^{11}cm^3.Plasma densities of 10^{13} cm^{-3} or higher are rarely achieved. High and very high density plasmas require high concentration of energy and as a result they tend to be non-uniform. Large area treatment is only possible in conjunction with substrate motion or designing an array of such sources.
- Again there is sometimes confusion on the terms ion and plasma source. In the simplest case, one can think of an ion source as a plasma source combined with an ion extraction system. The plasma is an ensemble of ions and electrons and neutrals, which is quasi neutral.
- During extraction, ions transition through a sheath region between extraction electrodes. The sheath's high electric field accelerates ions to a kinetic energy given by the sheath voltage time's ion charge. Large area ion extraction is commonly done via multi-aperture three-grid system of the acceleration-deceleration type, and such ion sources are known as "gridded" ion sources.
- Gridded ion sources offer the advantage of tightly controlled ion energy and dose but are not suitable to low energy due to space charge limitation of current density. For the large area work considered here, ion extraction is done either by a multi-aperture grid or multi-slit system. The characteristic size (hole diameter or slit width, respectively) must be smaller than the sheath thickness at the given extraction voltage and plasma density, otherwise the plasma will flow into the extraction gap and shorten it (the extraction voltage will "break down").
- Most ion sources of high energy (1 keV and greater) are gridded sources. The have a fundamental current limitation due to space charge in the extraction system. In planar geometry, the maximum current density is given by the Child equation

  $J = \chi V^{3/2}/d$ where $\chi = (4\varepsilon_o/9)(2e|IQ|/m)^{1/2}$
- χ is a material-specific constant, containing the charge state number Q and mass m, ε_o is the permittivity of free space, ε is the elementary charge, V is the extraction voltage and d is the distance between extraction electrodes, or equivalently, the sheath thickness.
- After extraction, the space charge of the ion beam attracts free electrons that are provided by a space charge neutralizer or generated by collisions with the residual gas, substrate, chamber wall, or other components. The ion beam quickly becomes space charge compensated, and only in the fully compensated state it will propagate in a near parallel beam fashion. Without space charge compensation, the ion beam will "blow up" and rapidly loose its original current density. The main difference between quasi-neutral plasma and the fully space-charge-compensated ion beam is the strong directed beam component in the ion velocity distribution function.
- Space charge limitation represents a fundamental problem

when low energy but (A more common way to circumvent current limitation is utilising ion acceleration that is not based on extraction. This is possible by generation of electric fields in magnetized plasmas. With *magnetized* one usually means that the motion of plasma electrons is governed by the magnetic field, i.e., electron gyrate around magnetic field lines, which greatly impedes their mobility perpendicular to the magnetic field lines, while the longitudinal mobility is not affected.

2. AN EXAMPLE OF A GRID-LESS, HEATER-LESS ION SOURCE

2.1 Advance Energy Single Ion Beam Source[20]

Fig. 10 shows the schematic reproduced from their brochure[20]. A dc voltage is applied to the anode. This voltage, combined with the high magnetic field between the tips of the internal and external cathodes, allow a plasma to start. Ions from the plasma are repelled by the anode electric field. This creates an ion beam with no grids or ion optics

Gridless ion-source technology avoids the expense, maintenance, and alignment problems that come with gridded sources. AE's ion beam sources avoid the tight-fitting alignment pins, very small screws, and loose alumina beads that come with gridded ion sources.

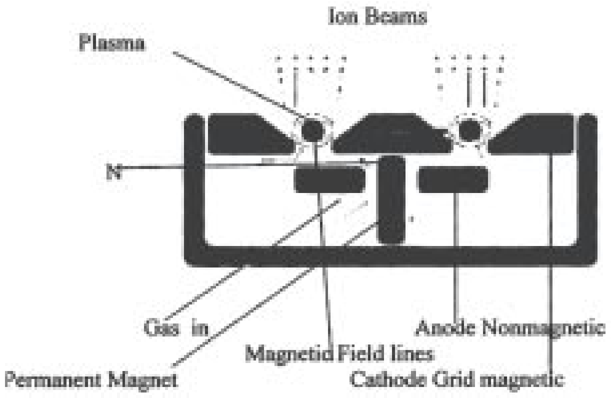


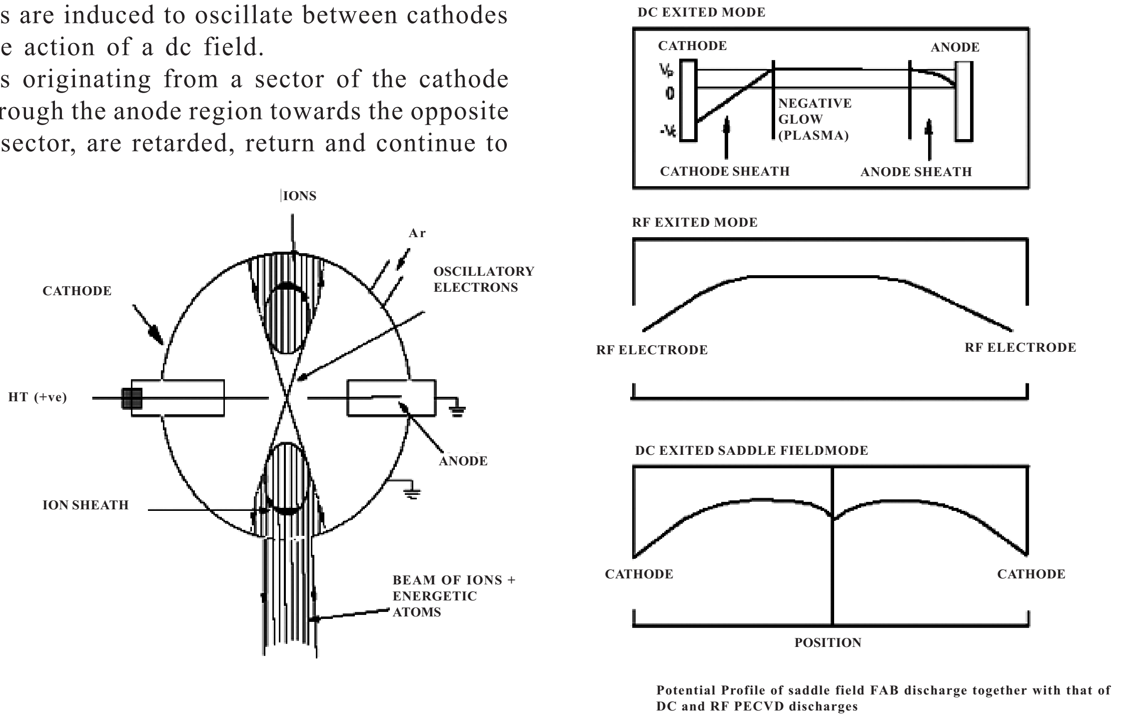
Figure 10. A schematic of advance energy single ion beem source.

2.2 Saddle Field Fast Atom Beam Source for Deposition & Etching (thinning) Applications

The working principle of a FAB source is shown in Fig 11. It consist of two anodes in the form of wires or rods (often Graphite or aluminum) surrounded by a cathode. When a dc positive voltage is applied to the source:

- Electrons are induced to oscillate between cathodes under the action of a dc field.
- Electrons originating from a sector of the cathode travel through the anode region towards the opposite cathode sector, are retarded, return and continue to oscillate about a central saddle point in the potential field.
- The electrons, therefore, describe long trajectories before being captured by the anode 4.
- A positive ion sheath exists near the cathode, which carries most of the discharge.

Voltage, apart from the relatively small drop in the potential at the cathode (s) and the plasma. The injected gas atoms are ionised and positive ions are formed. The positive ions are accelerated towards the cathode as a result of the potential difference between the ion sheath and the cathode. Thus, the cathodes allow self-extraction of the ions in the form of a beam when an aperture is introduced. The two proposed mechanisms of neutralisation of such ion beams are: the inherent arrangement of the electrostatic field close to the output grid helps electrons



Potential Profile of saddle field FAB discharge together with that of DC and RF PECVD discharges

Figure 11. Working principle of a fast atom beam source.

to recombine with the ions with little loss of energy, and the ions are neutralised by colliding with the residual gas molecules before passing through the aperture of the source. The saddle field fast atom beam source (FAB 110-2, Formerly Ion Tech. Ltd, now Atom Tech Ltd) characterisations studies have been carried out using argon (*Ar*), methane (CH_4) and acetylene (C_2H_2) as source gases. The details are given in our publication. It is to be noted that the DLC films grown this way show very low stress and are suitable for host of applications. At NPL, a process of thinning of a Electron microscopy specimen by use of saddle field source has also been developed. An indigenous source for the supply of such sources and complete system is M/s Omicron Scientific, New Delhi. They have already supplied a complete system to BITS, Pilani .

It should further be noted that a number of such Saddle field sources can be configured in a modular fashion to cover an increasingly large area.

Again glow discharge cleaning of substrates prior to deposition of a thin film is not a very satisfactory technique since it is done at a high pressure, and by the time one obtains a lower pressure, suitable for a thin film deposition in the vacuum vessel, the substrates become covered with impurities. It is often been found that though such a device is originally supplied with the vacuum coater soon its use is dispensed with however, the same very power supply with a little more sophistication incorporated and use of a easily fabricated saddle field source can undertake substrate cleaning, and much more. It is highly recommended that most laboratories involved in thin film R & D take notice of this possibility and indigenous supply of the equipment. Further, it is possible to increase the efficiency of such devices by incorporating a hollow cathode source in tandem. Such device for high energy applications are already in operation in many places in the world.

It has been proved that electrons and ions from electron-neutralised ion sources can cause damage in many substrate materials due to charge effects. Saddle Field Fast Atom Beam (FAB) sources produce a directed beam of charge free atoms and substrate damage due to beam charge is eliminated. FAB110 Saddle Field Fast Atom sources are cost effective sources for atom beam etching and sputtering all types of materials. Applications include substrate pre-cleaning for significantly enhanced film adhesion, sputter etching and atom beam sputter deposition with inert gases such as *Ar* or *Xe*.

Also reactive gases such as CF_4, SF_6, C_2F_6, C_3F_8, CHF_3, I_2, etc, are used for milling semiconductor materials at improved rate and high selectivity. With non-inert gases, the beam from the Saddle Field fast atom source may be molecular or contain radicals, but still largely remains uncharged.

Diamond like carbon (DLC) is an exciting modern material. It consists of an amorphous matrix of carbon and hydrogen atoms very largely linked in a tetrahedral structure like the carbon atoms in diamond. It is this structure that confers many properties of true diamond on this material.

2.3 Infra-Red Optics

Strongly adhesive, highly abrasion resistant infra-red transparent films make DLC the ideal material for coating lenses of germanium, silicon, quartz, etc. A thickness of 1.25mm provides an efficient (93%) anti-reflection coating on germanium for the 10.6 mm radiation from a CO_2 laser. At NPL a compete technology package was developed and transferred to a user agency for thermal imaging applications under Project Nag of DRDO using DLC .

2.4 Medical

Biocompatibility and blood compatibility together with high abrasion resistance and low friction properties may make DLC an ideal material for coating hip joints, heart valves and other prostheses. Tests in chemically and biochemically aggressive environments show prostheses to resist attack when coated with DLC.

2.5 Biochemical

A high attraction for mammalian and other cells plus visible transparency in very thin films (less than 50nm) and biocompatibility makes DLC an interesting material for coating tissue culture flasks, cell culture containers etc.

2.6 Mechanical

The properties of abrasion resistance, corrosion resistance, imperviousness and low friction make DLC the ideal coating for a variety of mechanical components operating under harsh and aggressive conditions.

A schematic of a saddle field source and actual photograph is shown below (Fig. 12, 14 & 15). It can easily be fabricated in any good mechanical workshop .The source in operation is shown in the photograph that follows (Fig. 13).

It has been proved that electrons and ions from electron neutralized ion sources can cause damage in many substrate materials due to charge effects. It is generally believed a Saddle Field Fast Atom Beam (FAB) source produces a directed beam of charge free atoms and, therefore, substrate damage due to beam charge is eliminated. FAB110 type Saddle Field Fast Atom sources are cost effective sources for atom beam etching and sputtering all types of materials. Applications include substrate pre-cleaning for significantly enhanced film adhesion, sputter etching and atom beam sputter deposition with inert gases such as Ar or Xe. Also reactive gases such as CF_4, SF_6, C_2F_6, C_3F_8, CHF_3, I_2, etc, are used for milling semiconductor materials at improved rate and high selectivity. With non-inert gases, the beam from the Saddle Field fast atom source may be molecular or contain radicals, but still largely remains uncharged.

Coating lenses of germanium, silicon, quartz, etc are needed for thermal imaging applications. A thickness of 1.25mm provides an efficient (93%) anti-reflection coating on germanium for the 10.6 mm radiation from a CO_2 laser.

Deviating from the largely accepted belief that Atom beam sources produce fully neutralised atom beams we investigated the beam coming out from such a source

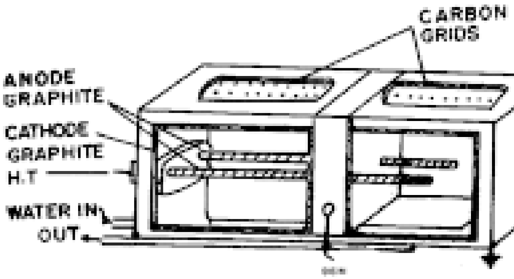


Figure 12. A schematic of a saddle field source and actual photograph.

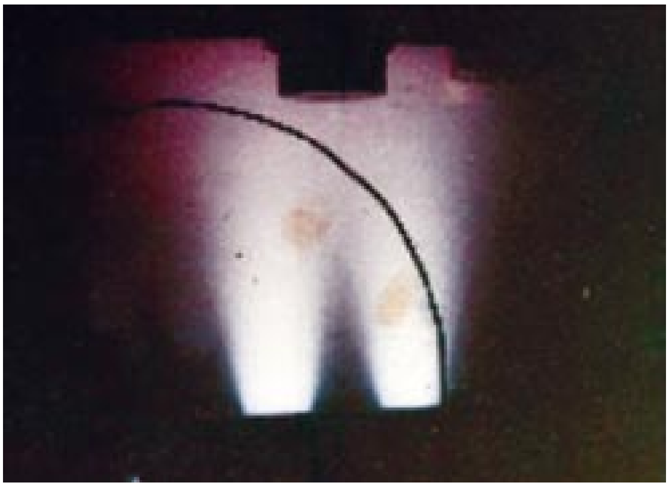


Figure 13. Saddle field source in operation.

using a deflector by innovating a new type of source as shown Fig 16. A Faraday cup was placed a different locations and beam current measured as shown in Fig. 17. DLC films grown at these two locations were investigated and were found to have different properties[4,5].

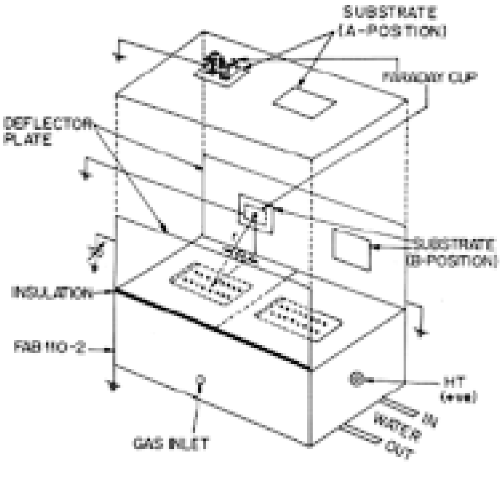
Variation of beam current density *vs* defector voltage at positions A and B using CH_4 as the source gas, at two different conditions of source operation (CH_4 partial pressure& 5.0x10~3 mbar kept constant).

Figure 14. Saddle Field sources manufactured by Atomtech Ltd[21].

Figure 15. Flange mounted saddle field sources.

2.6 DLC Films Produced Using a Saddle Field Fast Atom Source at NPL (registered very low stress and high hardness values as is evident from the figure above)

Author's group at NPL has done some pioneering wok in the area of DLC coating using Saddle field sources in the country. Some of our publications in this area are cited in the bibliography[4,5]. An Indian patent based on Saddle field fast atom beam source for ion beam etching-related processes was field by Rastogi, *et al* from NPL



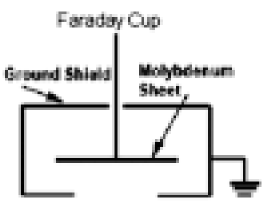


Figure 16. NPL innovation for deflecting the residual charges from a Saddle field source.

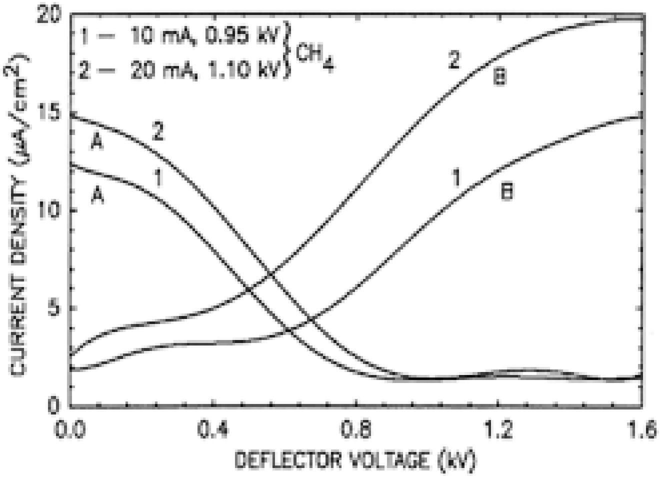


Figure 17. Result of plasma diagnostic of a Saddle field source analysis using a Faraday cup.

in 2001 (0208 DEL-2001). At NPL DLC-related R&D work has been going on for the last 2 decades, mostly using PECVD-based processes (Rf,VHF, microwave as also a dual- frequency based-process). The material so produced was tailored for thermal imaging applications (project NAG-DRDO) in the 8-12 micron range, for the coating of blade edges, coating of inside of bear bottles, etc. IIT, Delhi group is working on the application of DLC on compact discs under a industry-sponsored project,work is also in progress at Jadavpur university, ARCI-Hyderabad, BARC and other places. For Such applications, M/s VEECO, Advance Energy Group, NASA-USA, and others have developed ion source-based processes. It is felt in view of the work carried out at NPL already; Saddle Field sources can easily be adopted for coating of magnetic heads, CDs, etc.

2.7 Hollow Cathode Sources

Hollow cathode discharge in some ways resemble Saddle field sources , provides a very effective yet comparatively simple and cost-effective means of high density plasma at low enough working pressure.

As shown in the schematic below (Fig. 19), a hollow cathode device consists of two cylinders of metal, placed inside one another separated by a distance *d*, maintained at pressure *p*. A negative high voltage is applied to one cylinder and the other is grounded together with the vacuum vessel inside which the device is placed. As per Paschen's law, there is a particular, optimum *p* x *d* value, at which a discharge is conveniently generated. The discharge is other-wise weak and the density of ions low to be of any consequence, if the two reentrant cylinder design is not adopted. The conservation of particles and photons, in this particular geometry, leads to an increased ionisation and emission of ions. Electrons in the plasma get repelled when approaching the hollow cathode wall. Such an oscillatory motion of electron, similar in some way to what is obtained in Saddle field device, results in greatly improved ionisation and very high ion density. Hollow cathode can be operated by a Rf. source as well, one can incorporate a magnet and a thermionic heater as well .This behaves much like a Rf plasma reactor . In fact in tandem with a Saddle field source it can generate a completely neutral beam of atoms. One can, thus, realize a high density fast atom beam source of immense importance, using very simple construction and only Dc supplies. This is highly recommended for indigenous development. As can be seen most thin film laboratories in the country will benefit by this development. This can *in situ* clean the substrates, thin Specimens for electron microscopy examination, deposit DLC,(*a-Si:H*), Silicon nitride and host of other materials as well can be easily maintained by the operators or researchers. An exhaustive survey of published and patent literature is required before taking any commercial decision to develop further and manufacture what has been demonstrated in authors laboratory at NPL.

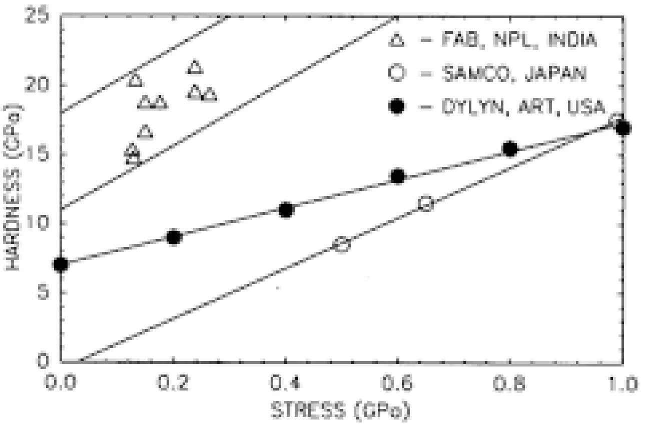


Figure 18. Hollow cathode sources.

Hollow cathode ion source working principle Adopted from the technical literature of HCD L-300, www.nanomaster.com, plasma consult shown in Fig. 19.

The hollow cathodes can have different geometries: tubes, arrays of tubes, or parallel plates (linear hollow cathodes).

2.8 Rf Ion Source

As has been mentioned earlier, an ion gun can often be visualised as a compact Rf plasma reactor for deposition or etching. A glow discharge is rather easily maintained at Rf frequencies in a reactor as compared to dc excitation of the plasma, which depends on secondary electron emission for its sustenance. A system of grids is then required to extract the ions and neutralize the same. This part is rather involved and one needs an insight into ion optics and also undertake modeling and simulation studies, using appropriate software, to precede any fabrication. One needs also a test bench to optimize the design. At NPL an in house project was undertaken sometime back and a degree of understanding as also initial enabling experiments performed. As for the continuous operation of the source,first and foremost requirement is an auto impedance matching network .Sadly such a device could not yet be developed in the country , although two versions of Solid state Rf. generators are now indigenously available (M/s Hind High Vacuum

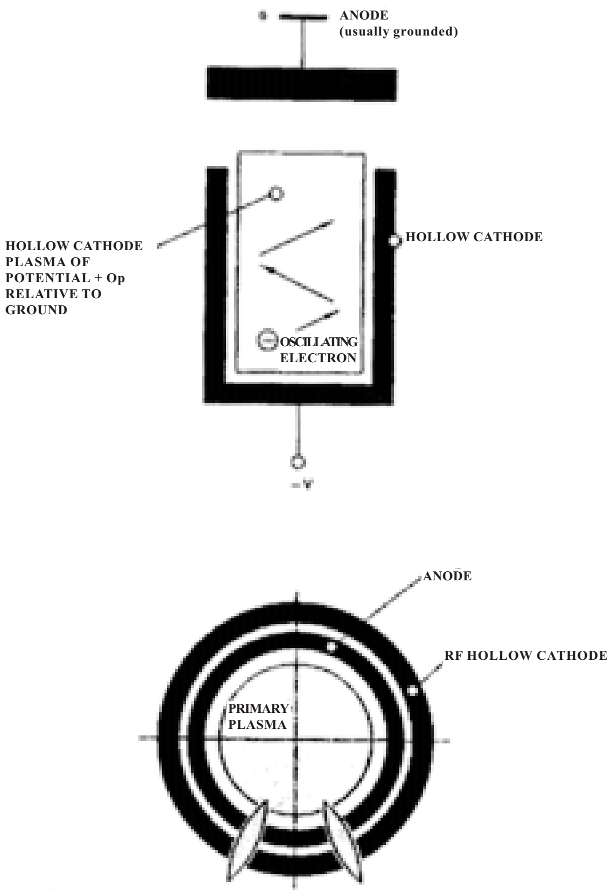


Figure 19. Hollow cathode ion source working principle.

Co under technology transfer through DST, NSC-NPL joint effort, other from M/S Omicron Scientific, New Delhi). Solid state generators working at VHF frequencies have also since been developed by NSC and supplied directly to the users on demand. It may be mentioned in the passing that plasma processing at VHF frequencies has now become accepted for amorphous silicon deposition for PV and other applications.

It is interesting to note that researches in developing Rf generators first were taken up for space applications in ion thrusters as also for injectors for fusion experiments. Some of the present successful commercial Rf sources of large area (35 cm) owe their origin to some pioneering work carried out at the University of Gieben by J. Freisinger[6], *et al.* The referred paper is of 1987 origin and mentions that Rf Ion thruster development preceded Rf ion source for material processing by at least 25 years. One recent paper on the subject is by D. Siegfried[7], *et al.* of M/s Ion Tech, USA, where development efforts of a 6 cm x 66 cm Rf ion source has been well documented. It may be noted for sputtering related operations a high enough beam energy in the range of 1000 eV is required. While as an assist source one would like to operate such sources at lower ion energies Commercial Rf ion guns, like the one mentioned above have been found to work both for Argon (sputter) and Oxygen (assist) in the energy range of 100-15000 e V, with beam current 1000 mA over an extended period of time.

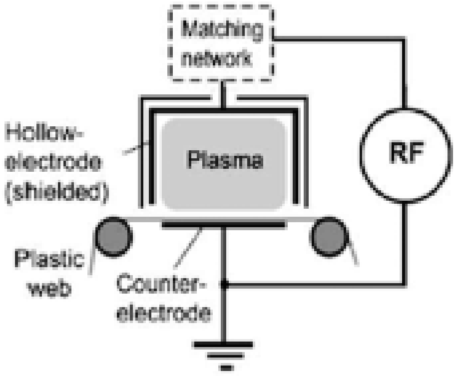


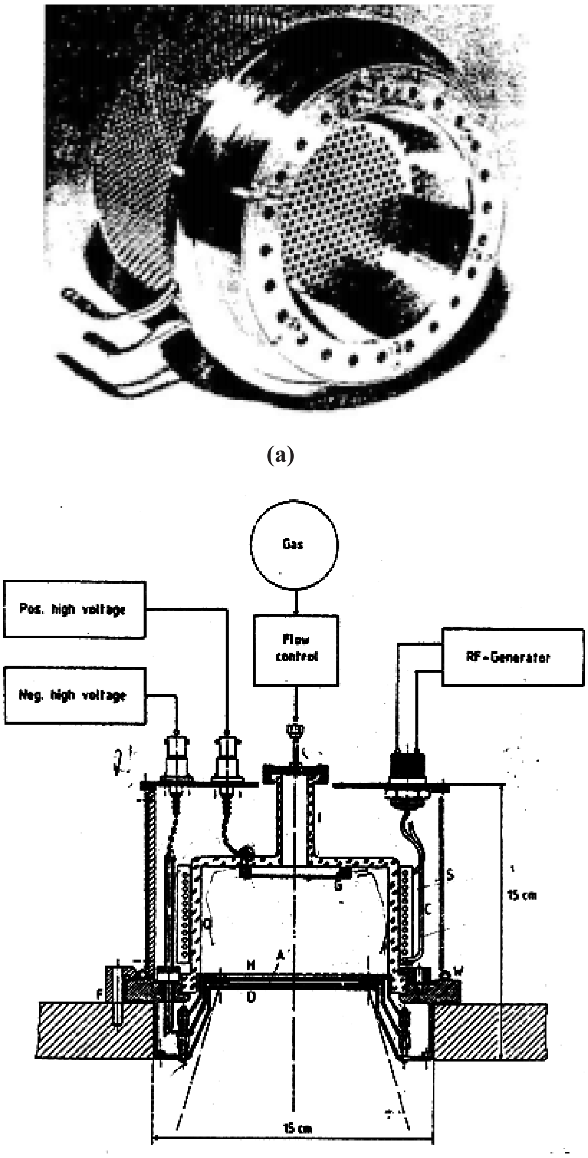
Figure 20. Adopted from the technical literature under[2].

Ion currents up to 300 mA could be drawn from RMI $^{-10}$ under stable operation (Fig. 21). The working point, however, depends upon available Rf generator output and pumping capacity of the vacuum pump used. For instance, one can operate at lower wattage of 320 watt at pumping speed of 10cm^3/min or 490Watt at 5 cm^3/min. In using ion sources pumping speed, not the ultimate vacuum obtained in the chamber is an important consideration, which seems to be over-looked at times. However, if one chooses to operate at lower beam currents, these conditions could be relaxed. Author strongly recommends to them, who wish to take up such development, to read these two paper carefully.

Further, to be able to extract the ion beam, which is offered by the Rf plasma and to accelerate the same by 3 grid system, a minimum extraction voltage will be necessary. In using ion sources pumping speed, not the ultimate vacuum obtained in the chamber is an important consideration, which seems to be over-looked at times. However, if one chooses to operate at lower beam currents, these conditions could be relaxed. Author strongly recommends to them, who wish to take up such development, to read these two mentioned paper carefully.

In India apart from some in-house R&D carried out at NPL, 13.56 MHz inductive coupled plasma (ICP) ion source for producing high brightness ion beams with very low energy spread has been developed at the Variable Energy Cyclotron Centre, Kolkatta. It is claimed to be a very compact ion source with external helical antenna wound around a 30 mm quartz tube. 1 mA of Argon and 0.5 mA of proton ion beams have been extracted from 2 mm dia aperture in plasma electrode at 4.0 kV extraction potential and ~200W of RF power. Using LabView software an automated plasma diagnostic system has also been designed and used to measure the plasma parameters. Retarding Field Analyser (RFA) has been designed and developed for ion energy spread measurements. This paper describes the features of the ion source, ion beams produced, and some results of the plasma diagnostics[13].

The schematic (Fig. 22) is of a VHF ion source operating at 80 MHz designed for high rate continuous deposition



(a)

(b)

Figure 21. RMI-10: (a) Rf ion source and (b) construction details.

of hydrogenated amorphous silicon for PV application[16]. Operating at such high frequency have many advantages and author's group at NPL have been a pioneer in this field at present in country there is much interest in this type of PV devices (BHEL,M/S Moser Baer,HHV PV). It may be noted, however, that though solid state Rf power sources are now indigenously becoming available , no auto-impedance matching units could be developed indigenously so far.The out-put impedance of the power supply is mostly 50 ohms, however the plasma impedance varies a great deal being-strongly-dependent on chamber pressure, temperature etc. Therefore, no worthwhile sputtering, PECVD, Etching (Rf or ICP) or ion-assisted deposition can be attempted in real life situations. A fast sensing of VSWR (in milli seconds) and corrections using motorised vacuum variable capacitors is indicated in such situations.

This needs to be urgently taken up for development

The scheme above is well suited for large area applications. In the scheme above a very high frequency of 80 MHz (VHF) has been employed.

2.9 Sources With Thermionic Emitters

The Kaufman source, one of the most successful ion source till date has an electron emitter. The Author has found the following description of another prototype laboratory device very instructive for one who wishes to embark upon such an ion source development[8] .

The discharge is obtained by applying a voltage between an electron-emitting hot-filament tungsten cathode, C and an anode cylinder A, (Fig. 23). Since the electrons are most effective in ionizing gases when their energy is low, the anode voltage is held at 30 to 60 V. At the source operating pressure, usually in the 10-2 Pa range, an electron emitted by the cathode must travel at an average of 1 meter before undergoing an ionizing collision. This distance is much greater than the discharge chamber dimensions. Therefore, to enhance the ionization efficiency, a coaxial magnetic field created by a solenoid is applied. One can thus set up a a broad-beam low-energy ion source, with a 2.5 cm nominal beam diameter intended for research and technology

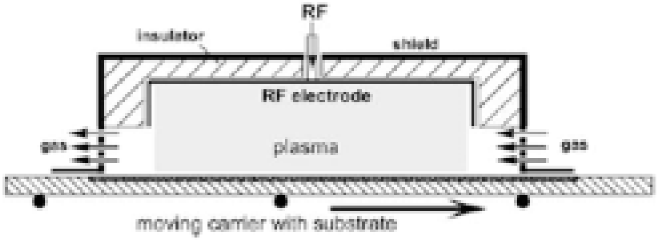


Figure 22. The schematic of a VHF ion source operating at 80 MHz designed for high rate continuous deposition of hydrogenated amorphous silicon for PV application[16].

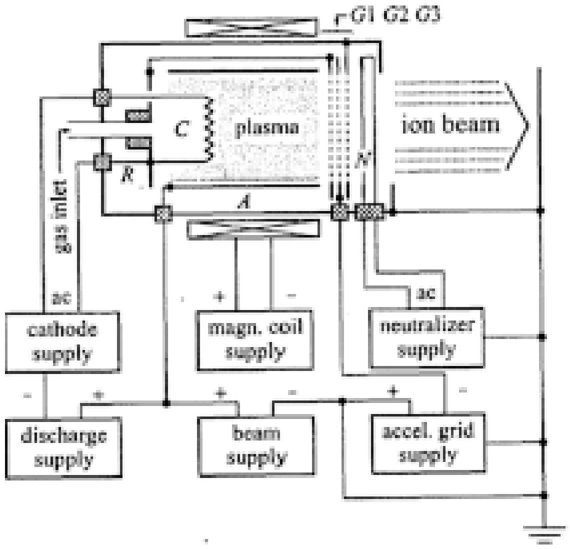


Figure 23. The discharge is obtained by applying a voltage between an electron-emitting hot-filament tungsten cathode, *C* and an anode cylinder *A*.

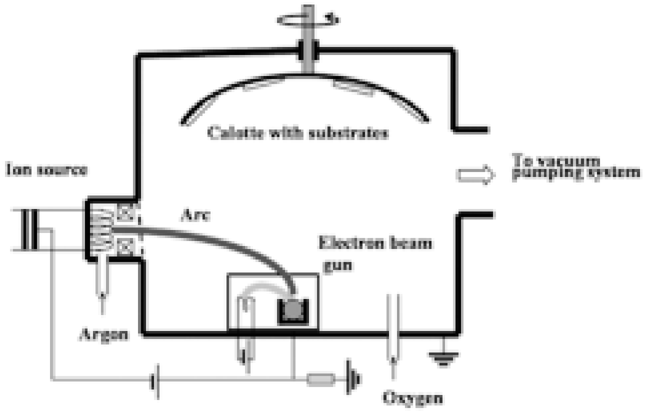


Figure 24. Balzers reactive low voltage ion plating.

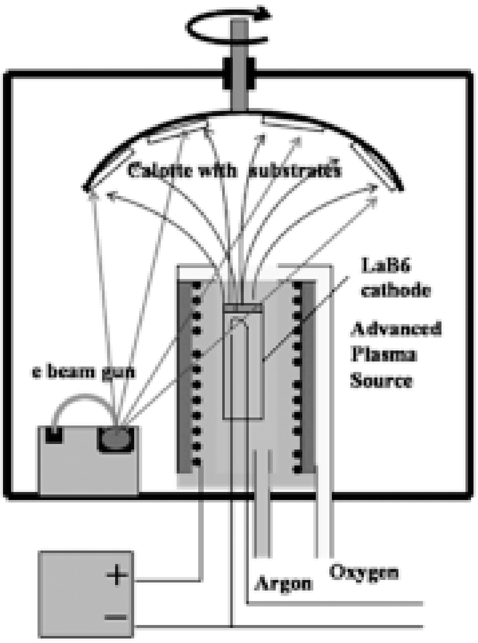


Figure 25. Leyold advanced plasma source.

applications. The operation of the source is based on electron impact ionisation in low-pressure gas discharge. Discharge and beam characteristics of the source were studied in different operating conditions. Two, types of extraction acceleration systems with different design were examined. For argon ions, at ion energies near I keV, ion beam densities up to 0.5 mA/cm^2, were achieved. The spatial uniformity index of the beam was evaluated to be about 0.5. The ion source was designed as an UHV-compatible autonomic unit.

The paper by Martev[8], *et al.* contains many technical details that may help a researcher looking for some specific application.

For sophisticated optical coating applications requiring films with dense microstructure and close to the bulk optical constants (refractive index and extinction coefficient) IBAD (ION Beam Assisted Deposition) technique has been perfected. It can be implemented either using two ion sources one for sputtering (ion beam sputtering) and the other for the ion assistance of the growing films on the substrate or using one e-beam source and other an ion source. One successful manufacturer uses two Rf ion sources for such application, one of higher ion energy for sputtering application. Balzers developed successfully what is known as reactive low voltage ion plating technique Fig. 24. Again, Leybold Optics have developed an interesting variation of the technique what is know as advanced plasma source (APS),which together with electron beam evaporation of various optical coating material has proven to be one of the most successful process for coating of ophthalmic as well as photonic and optical devices like filters for application in WDM communication. SATIS MC 380 Ophthalmic and Leyold CCS 250 and Ophthalmic is very popular ophthalmic lens-coating systems (AR-anti glare) which have an ion source.

Discharge voltage 30-150 volt dc, current 8-80A Cathode temperature -1600 ^{O}C.

The plasma source, APS, which is based on a large area LaB6 cathode, a cylindrical anode tube and a solenoid magnet, is located in the centre of the chamber bottom base plate Fig. 25. Very effective ionisation and activation of the evaporating coating material atoms from electron beam evaporator's takes place. The cylindrical LaB6 cathode is indirectly heated by a graphite filament. A dc voltage between anode and cathode creates a glow discharge plasma with a hot electron emitter, directed to the crucible (anode). The substrate holder is electrically insulated, in contact with the formed plasma in a noble gas such as argon. Due to the magnetic field, the electrons are extracted into the direction of the substrate holder .The substrates receive a relatively high negative self-biasing potential of 15-20 V. The reactive gases are introduced through a ring shower located on the top of plasma, which acts together with the repulsive force of the anode (crucible) as total volume of the chamber above the source the ions. The total pressure in the plant is in the low 10^{-3} mbar range.

Ion and plasma processes with controlled kinetic particle energy of some tens of electron volts are often preferred in reactive evaporative deposition for densification of the layers and improvement in adherence, hardness, abrasion resistance and stoichiometry. Ion beam-assisted deposition with various broad-beam ion sources, ion plating, particularly the reactive low-voltage ion plating process, and recently, plasma-assisted evaporative coating techniques, as the advanced plasma source process are used mainly for the production of various environmental stable dielectric multilayer products in instrument optics and ophthalmics. For extremely low-loss film products as for instance durable, all-dielectric mirrors, ion beam sputtering is today the most advanced technology. Mohan[9], *et.al* from IISC Bangalore and Pulker from Balzers group[10] and Sahoo[11] et al from BARC have authored excellent reviews on optical thin films produced by IBAD techniques.

WDM filters fabricated using Leyold APS ion source show (Figs 26 & 27) very little shift of peak (almost negligible) on the change of substrate temperature and insure fidelity

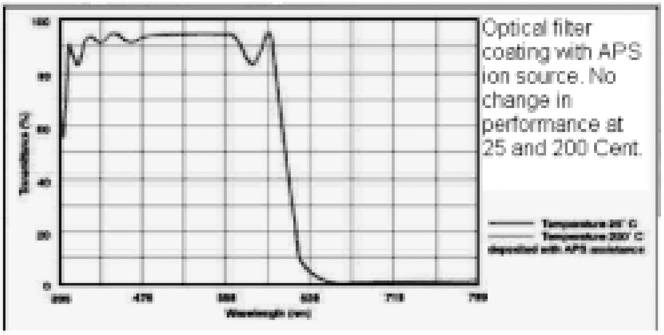
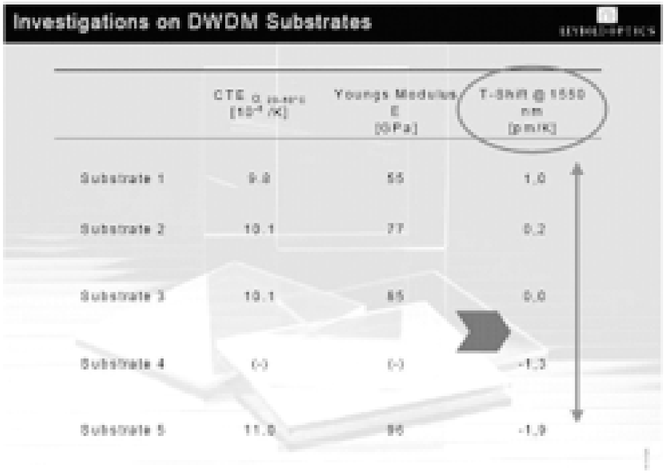


Figure 26. WDM filters fabricated using Leyold APS ion source show very little shift of peak (almost negligible) on the change of substrate temperature and insure fidelity of WDM transmission.



Investigations on DWDM Substrates

	CTE [illegible] $[10^{-6}/K]$	Youngs Modulus E [GPa]	T-Shift @ 1550 nm [pm/K]
Substrate 1	9.8	55	1.0
Substrate 2	10.1	77	0.2
Substrate 3	10.1	85	0.0
Substrate 4	(-)	(-)	-1.3
Substrate 5	11.0	86	-1.9

Figure 27. Results of investigations on DWDM substrates.

of WDM transmission (www.leyboldoptics.com)

M/S Leybold Optics have also developed an ion source based process and system Safire for producing well adherent *AR* coatings which helps water droplets to roll-off. In this country, most such coatings are presently imported .This business opportunity need to be recognised and exploited having indigenous equipment and processes secured with patents .We in the country at the moment produce only low end of such coated products. (information for Figs 25-27 adopted from M/S Leybold optics technical literature).

2.10Arc-ion Source

Vacuum plasma arc technique is very popular for hard decorative coatings. Multarc in India has pioneered this technology. At NPL, we have for last almost a decade worked on tetrahedral amorphous carbon thin films and a major project (DST) involving M/s Mutiarc is to be launched soon.

The schematic of a vacuum Plasma arc process is shown in Fig. 28(a). An arc is generated by touching the cathode of the material to be evaporated momentarily with a striker. The arc in sustained by the energetic ions produced during the arcing process. A low voltage high current supply with some special features is required for such systems.

Vacuum plasma arc can produce highly ionised plasmas from virtually all solid (or even liquid) metallic elements. As long as a material is sufficiently conducting to serve as an arc cathode, it can be used in a cathodic arc discharge; therefore, not only metals but only semi-metals (graphite), highly doped semiconductors (*Si, Ge*), and hot semiconductors have been used to produce plasma from which ions can be extracted.

Cathodic arc plasma is characterised by the presence of multiply charged ions. Ions formed in the plasma can be extracted and accelerated by the strong electric field between extraction electrodes. It is high time a system is developed and offered for a variety of metallic and non metallic target materials, much like the magnetron sputtering targets. One can also think of flange mounted units for upgrading existing PVD reactors by retrofitting, as shown schematically in Fig. 29. Fig. 28(b) shows how using a filtered arc ion source large area substrates can be coated.

These filtered arc vapour plasma sources are designed to meet the diverse needs of customers, either retrofitting with existing PVD chambers (Fig 29), or as a source component within advanced surface engineering equipment. Credit: info@arcomac.com.

3. HIGH DENSITY PLASMA SOURCES

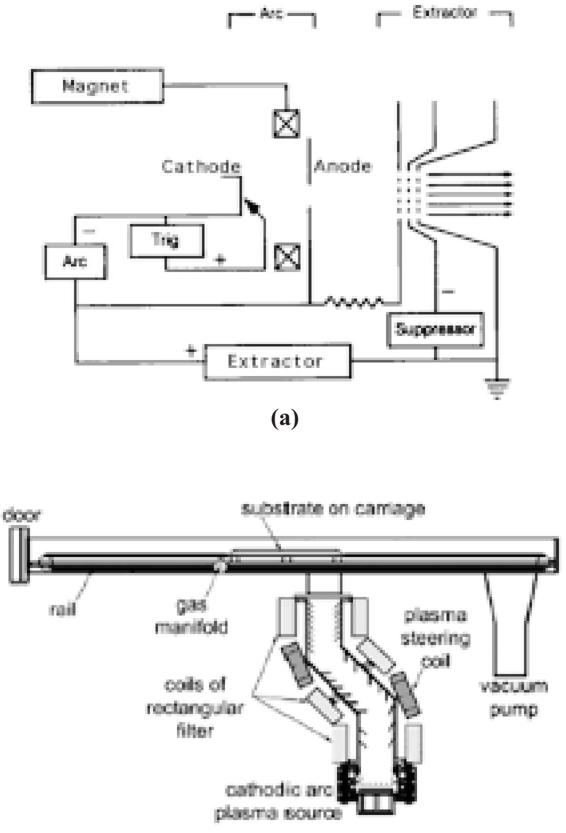
Plasma-based materials processing including applications in semiconductor and microsystem technology often require high densities (> 1011 cm^{-3}) of electrically charged (ions, electrons) and uncharged particles such as excited species and radicals. Additionally, a good plasma uniformity over larger diameters (200 mm) is required. In certain applications one is also interested in low ion energies (< 20 eV) to avoid substrate damage.

Increasing demands in modern thin film technology for higher plasma densities at simultaneously lower process pressure and lower ion energy and independent control of ion energy and ion current density require plasma sources with high performance. These requirements are fulfilled by ECR and ICP sources.

ECR is an electrode less source in a magnetic field where the discharge intensifies substantially when the conditions for electron cyclotron resonance are fulfilled. (the electron cyclotron frequency). For the microwave power from a commercial microwave power supply with f = 2.45GHz the resonance condition ($f = f_c$) is fulfilled for a magnetic field strength of 0.0875 T. The microwave power absorption will reach maximum where the magnetic field reaches this value and a discharge will be generated mainly in this area.

ECR and ICP sources [Figs 30(a) and (b)] develop some excellent features for low pressure plasma processing, such as:

- High degree of ionisation
- Low process pressure of $<10^{-3}$…0,1 mbar, high densities of ions, radicals and excited particles also in the low pressure range $<10^{-3}$ mbar
- Low contamination because no electrodes are needed
- No restriction for operation on reactive and corrosive



(a)

(b)

Figure 28. (a) Schematic of the plasma generator (cathode-anode arc discharge, trigger for starting the arc, and three-grid extraction system based on the acceleration-deceleration principle[15] and (b) using a filtered arc ion source large area substrates can be coated.

gases

- Independent control of ion energy and ion current density
- Low damage of the substrate surface because of the low ion energy in the plasma gas flows through the ion source between the anode and cathode. A positive Plasma-based materials processing including applications in semiconductor and micro system technology often require high densities (> 10^{11} cm^{-3}) of electrically charged (ions, electrons) and uncharged particles such as excited species and radicals. Additionally, a good plasma uniformity over larger diameters (200 mm) is required. In certain applications one is also interested in low ion energies (< 20 eV) in order to avoid substrate damage.

Figure 29. These filtered arc vapour plasma sources are designed to meet the diverse needs of customers, either retrofitting with existing PVD chambers.

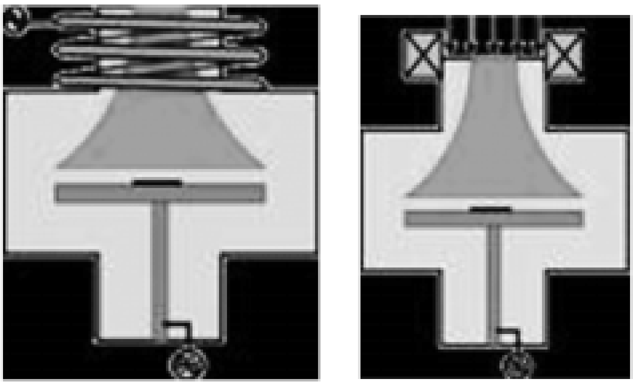
3.1 Inductive Coupled Plasma

Inductive Coupled Plasma www.oxfordplasma.de [Fig. 30(a)].

3.2 Electron Cyclotron Resonance

Electron Cyclotron Resonance www.oxfordplasma.de (Fig. 30(b)

A dual frequency (Microwave Plasma+ Rf Bias) PECVD reactor has been developed at NPL. Here plasma generation and bias application to the substrate processes can be separated, much like an ion beam source. Using this reactor it has been possible to grow, DLC, nano diamond and CNT films in the same reactor, at different parameter space, since microwave power application and Rf bias application to the substrates can be independently controlled in such a reactor. The similar facility is provided in an ICP source as discussed above. From the schematic of the ICP reactor as given below (Fig. 31) that there are two matching networks.



(a) (b)

Figure 30. (a) Inductive coupled plasma and (b) Electron Cyclotron Resonance.

To have tight control of the process it is essential that the two networks be auto matched. This then becomes an independent task to be accomplished on priority. Therefore, even though fully solid state Rf power supplies have become commercially available in the country for last several years , for real life applications all such sources continue to be imported.

3.3 END Hall Ion Source

In the very beginning of this paper the authors have shown how Space thrusters use End hall sources for their propulsion they end this report by presenting a brief account of such sources adopted for DLC coatings.

End-Hall ion sources are well suited to applications where large currents of low-energy ions are utilised to assist thin film deposition. This process increases adhesion, modifies stress, increases density and hardness, produces a preferred orientation and improves step coverage. Additional process benefits include the ability to:

ICP REACTORS

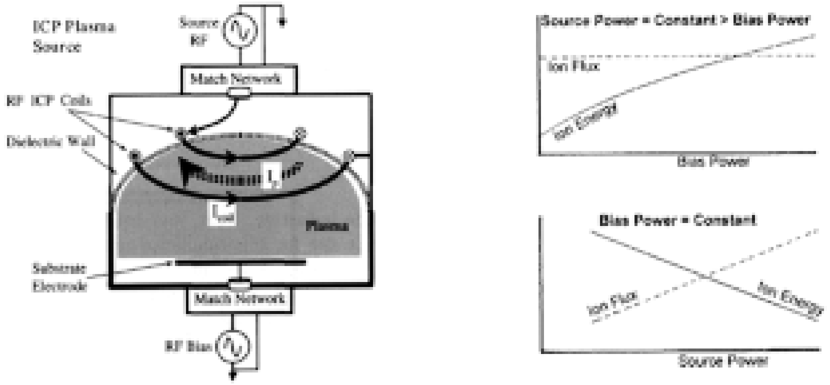


Figure 31. ICP Ion source development require two Rf generators properly matched CSIO ,Chandigragh is working on ICP based DRIE system.

- Lower deposition temperature
- Maintain low background pressures(<1 x 10^{-4} mbar)
- Eliminate substrate biasing
- Provide run-to-run repeatability

The technical design of the End-Hall ion source has been well developed, and its operating mechanism is well understood. The End-Hall is named because the ion beam exists the acceleration region at the circular end of the magnetic field as described by Kaufman[14], *et al*. Recently, the circular End-Hall ion sources were arranged to form a linear version for large area plasma treatment. End-Hall ion source design can form a glow discharge in the region as shown in the Fig. 32.

The magnetic field lines cross the electric field lines so that the electrons can move in circular trajectories to generate the so called Hall current. Reactive gases are injected from bottom of the ion source as shown in the Fig. 32.

An End Hall source for DLC work also suited for substrate cleaning and an assist source for IBAD work.

An End Hall ion source (Fig. 32) was optimized for DLC coatings by Pan & Yin[12], yyin@physics.usyd.edu.au, in the Fig. 33. One notes that there is an optimum energy at which DLC films are the hardest. This can be easily realised in the process that can tailor the ion energy like the present one. We could achieve this tailorability otherwise in a PECVD reactor operating at two frequencies simultaneously, microwave and Rf. (for bias). This will be also possible in an ICP reactor or ion sources working with 2 Rf sources (13.56 MHz) as shown in the figure. Both need to be auto-matched for consistent and long run-time application auto-matching of Rf sources needs to be urgently addressed since we are in a position to produce commercially such Rf power supplies.

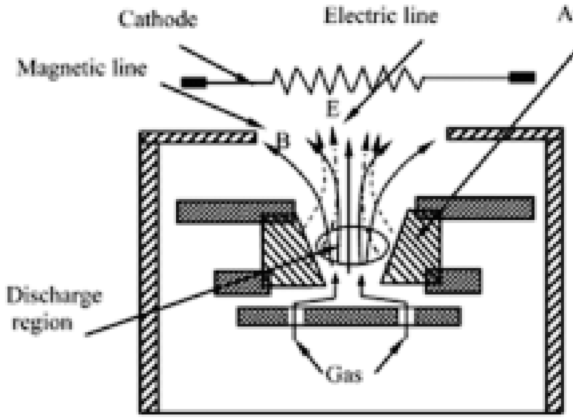


Figure 32. End-Hall in source ophmissed.

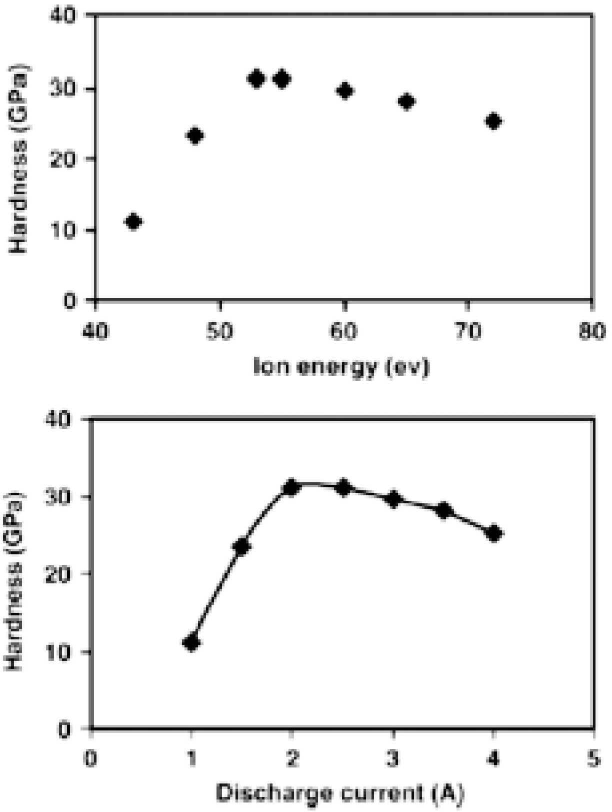


Figure 33. An End-hall ion source optimised for DLC coatings[12].

4. CONCULUSION

In this paper, essentially author has reviewed some of the recent trends in ion source development for thin film R&D and then went on to record all the efforts, big and small, that have been made or are being made in the country to have such devices developed. It has been shown that a reasonable degree of competence in designing and fabricating plasma reactors of various kinds have been demonstrated at NPL, CEERI, and are being manufactured by M/S HHV, Bangalore and others.The essential knowledge of plasma source design and testing also exists in some places ,very rudimentary plasma sources are also beginning to be commercially available. By taking a proactive attitude to the entire development, an initiative from some funding agency like DST can yield the desired results.What is required is to pool all such knowledge and apply the accumulated knowledge and techniques to solve the technological problems at hand relating to the development of plasma sources for thin film R&D. Development of related power supplies also need focused attention. The author recommendations:

1. A cluster of professionals who have diverse expertise and experience in the area of ion sources for Space thrusters, accelerators, plasma fusion R&D and thin film and vacuum technology is identified by a funding agency like DST, specifically to chart a blue print for indigenously designing and developing such sources in consultation with user industries. A place like CEERI, which has years of vacuum tube development track record may be made a hub for this development. A centre of the type M/S Kaufman & Robinson, which is knowledge and skill-based and provider of basic technologies in this field to vacuum and thin film equipment providers in the country appears to be the need of the hour.
2. The following sources needs to be taken up for development;
    a. Saddle field fast atom beam source
    b. dc gridded ion sources of various types.
    c. End-hall ion source
    d. Hollow cathode ion source.
    e. Rf & VHF ion sources.
    f. Inductive coupled plasma.
    g. ECR ion source.

    Perhaps, in the same order or forming sub groups to launch three parallel efforts. In-depth knowledge of ion optics and various simulation and modelling software is deemed essential to succeed in this effort.
3. Indigenous development of coating systems for ophthalmic applications using Ion sources as also professional optical coatings for demanding applications like WDM filters for optical communication, laser mirrors with very high damage threshold, various edge filters, dichroic and trichroic filters as also DLC coatings for thermal imaging, etc are taken up and demonstrated to earn the confidence of discerning user in defence and aerospace. This is a very large industry sector with a consumer base but without the ion source becoming indigenously available, one can not see how we can internationally compete in this area. Similarly, all sophisticated optical thin film coaters in this country, mostly with defence and aerospace labs, are imported each costing somewhere between 4-5 crore, and invariably have one or more of such advanced ion sources. Though a lot of coating knowledge has been generated at places like NPL, IISC, BARC, CAT, IUAC and many defence and aerospace laboratories for their in-house use, no commercial exploitation of the same involving indigenous equipment has yet been taken up.

Author feels with all the experience, skills and expertise at various locations in the country this should be possible and need necessarily to be attempted as a network project.

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Contributor

Dr R. Bhattacharyya took his PhD from IT, BHU in the year 1971. From 1972 onward he has been with the National Physical Laboratory, New Delhi. He superannuated in the year 2003 and then worked at various places to return again to NPL in January 2006 as an Emeritus Scientist and worked till September 2008 in that capacity. All his professional life he has been involved with the practice of Science & Technology of Thinfilms. He has been the key person to initiate Plasma based processing of Thinfilms at NPL which developed as a major activity in later years. He has guided some 8 students for PhD/MTech and published more than 110 papers, delivered numerous invited talks and has PECVD related process patents to his credit. He was involved in developing complete technology packages for Space Qualified Professional optical coatings for ISRO & HAL (licensed to 2 firms), Amorphous Silicon based PV, X-ray detectors, OASLM, DLC coatings for Project NAG of DRDO, Multilayer metallization of phase shifters for RADARS(Akash-DRDO) and a large number of other coatings for photonics ,MEMS & Sensors and Nano technology requirements. He has been awarded by NRDC and MRSI (Medal Lecture).