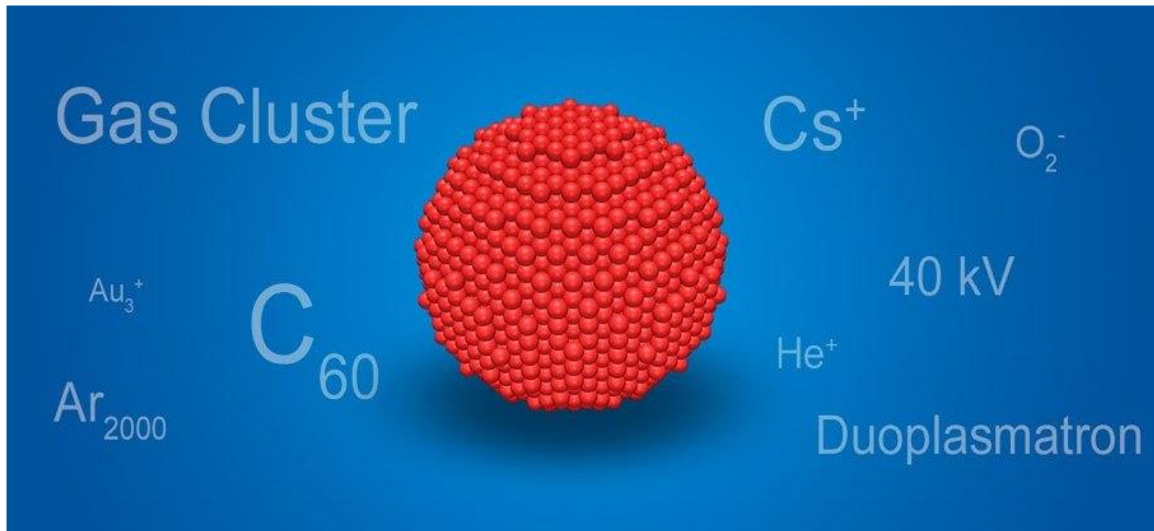

Ion Beams and their Applications

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ION BEAMS COME IN MANY SHAPES AND SIZES; DIFFERENT SOURCE TECHNOLOGIES PRODUCE A WIDE RANGE OF DIFFERENT BEAM TYPES, SOME HAVE FLEXIBLE SOURCES THAT CAN ACCOMMODATE A RANGE OF ELEMENTS, WHILE SOME ARE BROAD BEAMS, AND SOME ANALYTICAL. IT CAN BE A MINE FIELD IF YOU DON'T KNOW WHAT YOU'RE LOOKING FOR. IN THIS APPLICATION NOTE, WE SHED LIGHT ON IONOPTIKA'S RANGE OF ION BEAMS.

1. Sputter vs. Analytical Ion Beams

Ionoptika's range of ion beams can be split into two groups based on their applications or purpose; sputter beams, and analytical beams.

Sputter Beams

While all ion beams will sputter a surface, we make this distinction based on the area and speed with which this occurs. Sputter beams have three characteristic features: high current, large spot size, and wide field of view. They are designed to deliver a large dose of ions over a wide area as quickly as possible, in order to optimize etch rates.

Sputter beams are often used to remove material prior to analysis using a separate analytical technique, e.g. SIMS, XPS, SEM, TEM, Auger etc. This can be for cleaning purposes, or used as a means of depth profiling through the sample.

Analytical Beams

Rather than being used to facilitate analysis using a separate technique, analytical beams are designed to perform the analysis themselves. They also have three characteristic features; wide energy range, small spot size, and variable current control. This gives the user incredibly fine control over the beam characteristics, which enables them to optimize their experiment.

Analytical beams are primarily used for mass spectrometry, for example SIMS (secondary ion mass spectrometry), and have also been installed on MALDI (matrix assisted laser desorption ionization) instruments.

2. C60 Beams

Carbon-60, or just C60, is a type of fullerene molecule, consisting of sixty carbon atoms formed into a hollow sphere, not unlike the shape of a soccer ball. The first C60 ion beam was produced by Ionoptika, in collaboration with the University of Manchester in 2002, and since then more than 140 units have been sold worldwide.

Compared to monatomic ion beams, C60 beams result in a much “gentler” sputtering action, greatly reducing the damage caused to sub-surface layers. Preferential sputtering – normally an issue for monatomic beams – is largely non-existent for C60, while the etch rate of is also relatively consistent across different material types. This makes C60 a very powerful, very consistent sputter source.

As an analytical beam, the gentle sputtering action of C60 also reduces the fragmentation of larger molecules, resulting in an enhanced molecular signal intensity. For techniques such as SIMS, this can be incredibly important, as it significantly increases the usable mass range of the technique.

3. Gas Cluster Ion Beams

Gas cluster ion beams (GCIB) are high-energy beams of cluster ions, ideal for the sputtering and analysis of organic matter. They are an incredibly versatile ion source, as both the beam-type and the properties of the beam can be varied as needed. This allows the user to tune the beam to the needs of their experiment.

The source operates through the adiabatic expansion of gas in a vacuum, causing rapid cooling and resulting in cluster formation. The clusters are then ionized through electron bombardment and accelerated through the column. The size of cluster is a vital parameter, and may be tuned over a wide range by adjusting the source conditions.

GCIB for Organic Analysis

GCIBs are the ideal choice for sputtering organic matter. Etch rates of organic materials are several orders of magnitude higher than metallic or semiconductor materials. This makes cluster beams such as the GCIB 10S an excellent tool for cleaning surfaces prior to analysis. The large cluster species also produce very little fragmentation or sub-surface damage – performing better than C60 on both fronts.
In order to maximize the benefits of GCIBs for SIMS, the beam must be operated as high energy. This is because the secondary ion yield shows a non-linear increase as a function of beam energy. We therefore currently offer two variants of analytical beam: the 40kV GCIB 40, and the 70kV GCIB SM.
The J105 SIMS utilizes the benefits of gas cluster beams for organic analysis. The combination of the gentle sputter action of large cluster ions with increased secondary ion yield has extended the usable mass-range to > m/z 2500.

Choice of gas

The versatility of GCIBs comes from having a choice of input gas. Argon has historically been a favorite, as it is an inert gas that forms clusters easily.
Ar/CO_2 mixtures are also common – the CO_2 acting as a cluster formation agent.
However pure CO_2 gas is now the favored option for many of our customers using GCIBs for SIMS.
The stronger van der Waals forces between CO_2 molecules results in much larger clusters than would be available for Ar – up to 20,000 in some cases. This gives users much greater control over the all important E/n value (energy per nucleon).
Researchers have shown that optimizing E/n results in an enhancement of the secondary ion signal. It is also thought that the presence of O^- ions at the surface improves the probability of ionization – further enhancing ion yield.
We have recently developed a water vapor (H_2O) source for GCIBs. This is currently available as an optional add-on for our GCIB-40 and GCIB-SM products.

4. Liquid Metal Ion Beams

Liquid metal ion beams, also known as LMIS, or LMIG, are a well established source technology. The source operates by a liquid metal reservoir feeding a blunt tungsten tip, from which ions are extracted by a strong electric field. The source design is elegant and reliable, and hence has been used in focused ion beam (FIB) systems for decades. Ionoptika offer a 25 kV LMIG system in two variants; the IOG 25AU gold-cluster system, and IOG 25GA gallium system.
Liquid metal beams produce monatomic or small-cluster ion beams, such as Au^+, Ga^+, and Au_3^+. As such, they are characterized by very small spot sizes (< 100 nm). This makes them ideal for high-resolution analysis applications.

The high-energy smaller ions can penetrate, or channel, far beneath the surface before dissipating their energy. This causes significant sub-surface damage, and as

such depth profiling can be unreliable. It also results in significant fragmentation, making LMIG sources much more suited to the analysis of hard materials.

5. Duoplasmatron Ion Beams

Duoplasmatrons are an incredibly high-brightness ion source. The ions are generated as gas is slowly fed into an arc chamber, where it ignites as plasma. The plasma is then extracted and focused through the column. The nature of the source allows for many different source gases to be used. This means that duoplasmatron sources are a highly flexible source of ions.

Duoplasmatron ion beams are monatomic, and do not form clusters. This however results in much lower energy distributions, enabling smaller spot sizes. Combined with a high-brightness source, this leads to a very high current density beam, ideal for hard materials or where fragmentation is not a concern.

Ionoptika produce two variants of the duoplasmatron ion beam: the FLIG® 5 – a low energy sputter source, and the IOG 30D – a 30 kV high-current analytical beam.

FLIG – Floating Low Energy Ion Beam

The FLIG® 5 is a unique ion beam system as it is based on floating column design. The design enables very low energy operation (down to 200 eV), while still delivering high current. Operating at such low impact energies greatly reduces the penetration depth of the beam, which in turn improves the depth resolution. Both O_2 and Cs variants of the FLIG are available.

6. Conclusion

The table below compares Ionoptika's various ion beam products under a number of categories discussed in this article.

Analytical Ion Beams:

Product	Species	Energy Range	Max Current	Min. Spot Size	Source Lifetime	Ideal For
IOG 25GA	Ga^+, $^{69}Ga^+$*	5 — 25 kV	> 10 nA, or > 50 nA†	< 50 nm	> 400 hrs	Inorganic materials, FIB applications
IOG 25AU	Au^+, Au^{++}, Au_2^+, Au_3^+	5 — 25 kV	> 10 nA	< 100 nm	> 400 hrs	Inorganic materials
IOG 30D	Ar (and other noble gases), O_2, N_2, Cs*	5 — 30 kV	> 500 nA @ 30 kV Ar^+	< 500 nm @ 30 kV Ar^+	> 400 hrs	Inorganic materials
GCIB 40	Ar_n, $(CO_2)_n$, $(H_2O)_n$*	10 — 40 kV	> 300 pA @ 40 kV $(CO_2)_{4k}$	3 µm @ 40 kV $(CO_2)_{4k}$	4 — 6 months	Organic, biological materials
GCIB SM	Ar_n, $(CO_2)_n$, $(H_2O)_n$*	20 — 70 kV		1 µm @ $(CO_2)_{10k}$	4 — 6 months	Organic, biological materials
IOG C60-20	C_{60}^+, C_{60}^{++}, C_{60}^{+++}	5 — 20 kV	> 2 nA @ 20 kV C_{60}^+	2 µm @ 20 kV C_{60}^+	4 — 6 months	Mixed materials (inorganic/organic)
IOG C60-40	C_{60}^+, C_{60}^{++}, C_{60}^{+++}	10 — 40 kV	> 1 nA @ 40 kV C_{60}^+	300 nm @ 40 kV C_{60}^+	4 — 6 months	Mixed materials (inorganic/organic)

* Requires special source
† Requires high-current option

Sputter Ion Beams:

Product	Species	Energy Range	Max Current	Min Spot Size	Source Lifetime	Ideal For
FLIG®5	O_2, Cs*	0.2 — 5 kV	> 500 nA @ 5 keV	< 15 µm @ 5keV 500nA	> 400 hrs	Semiconductor, inorganic materials
IOG C60-10	C_{60}^+, C_{60}^{++}, C_{60}^{+++}	1 — 10 kV	> 40 nA C_{60}^+ mass filtered	< 1 mm	4 — 6 months	Mixed materials (inorganic/organic)
IOG C60-20S	C_{60}^+, C_{60}^{++}, C_{60}^{+++}	1 — 20 kV	> 50 nA $C_{60}^+ + C_{60}^{++}$ combined beam	< 100 µm	4 — 6 months	Mixed materials (inorganic/organic)
GCIB 10S	Ar_n	1 — 10 kV	> 15 nA @ Ar_{1000}	< 200 µm @ Ar_{1000}	4 — 6 months	Organic, biological materials

* Requires special source

Tags: applications, beams, c60, duoplasmatron, gcib, ion, lmig, sputter, tofsims