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TECH BRIEF

An Introduction to Ion Beam Etching

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INTRODUCTION

The Electronics industry is demanding increased product density, increased yields, and tighter tolerances. Ion Beam Etching (IBE) technology meets these challenges by providing a capability to produce line widths and dense structures to micron levels, with high yields and minimal pattern variations. Price factors have always made conventional isotropic chemical etch processes the dominating etching technique used in the industry. However, Chemical etching techniques can produce lifetime limiting defects due to contamination, undercutting of films, chemical reactions with other materials and general surface roughening and pitting. For these reasons, Ion Beam anisotropic etching technology is rapidly becoming the etching technology of choice for many high-density applications. Our hope is that a better understanding of ion milling will allow technologists the ability to apply it effectively and reliably.

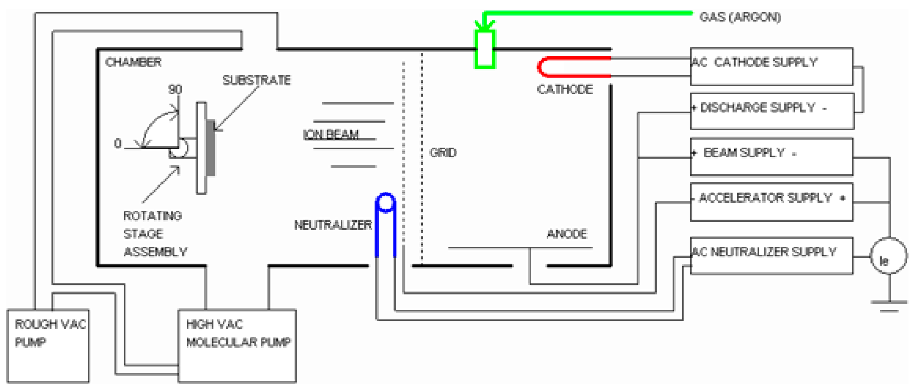
ION BEAM SOURCE

An Ion Source generates a broad Ion Beam directed at the substrate (or product to be patterned). The most common broad beam source is the Kaufman (grid) type illustrated in **Figure 1**. Ions are generated in a discharge chamber where atoms of a gas (Argon) are ionized by energetic electron bombardment. Electrons are emitted from a cathode filament and collected by the anode. A magnetic field is used to contain the electrons and increase the probability of ionization. The bombardment of electrons with gas atoms forms a conductive gas or plasma. A negatively biased grid is used to accelerate ions that pass through the grid to form the ion beam. After the accelerator grid, a Neutralizer filament is used to introduce electrons to balance the positively charged ions. The beam current and voltage can be independently controlled to obtain the desired ion energy (expressed in electron-Volts) and beam current density (expressed in Amperes/cm2).

A vacuum of 10-6 Torr to 10-5 Torr is accomplished with a roughing pump and a high vacuum molecular pump. The vacuum is required to produce the Ion Beam plasma as well as minimize contamination to the substrate during the etching process. A pressure of 10-4 Torr is typical while the Gas is flowing to produce the Ion Beam.

The substrate is typically mounted onto a Rotating Stage assembly. Several axis of rotation are employed to achieve a uniform etch profile and to also control the angle of incidence of the ion beam.

Figure 1: *Ion Beam Etch System Diagram*

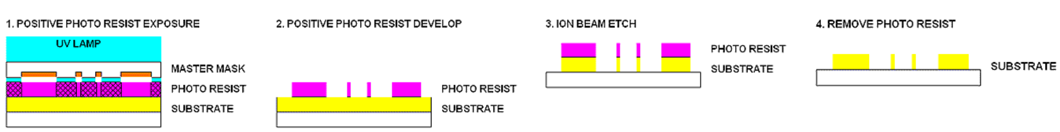


ETCHING BASICS

IBE is an anisotropic etching process that faithfully reproduces the mask pattern on the product. An Ion Beam is used to sputter etch material exposed by a mask (typically a photo resist) to obtain the desired pattern.

Patterns are superimposed onto a substrate using thin film technology. Photo resist is spun onto the substrate and cured (soft bake). A Chrome on Quartz master mask is used to transfer the desired pattern onto the photo resist layer. For a negative mask resist, an Ultra Violet (UV) lamp source photo-polymerizes [2] the photo resist areas exposed by the master mask. After exposure, the un-exposed photo resist is washed away with a developer solution. A positive mask exposure is the inverse process where the UV exposed photo resist (poly-imid) is developed and washed away. Once the excess resist has been washed away, the substrate is cured in an oven (hard bake) and then mounted onto a fixture for Ion Milling. This process is illustrated in **Figure 2**.

Figure 2: *Photolithography*



Ions that impact the exposed material with sufficient energy will dislodge atoms or molecules. The number of atoms etched by each ion is referred to as the "Sputter Yield" [1]. This process also generates significant heat. Cooling is required to ensure that the substrate temperature does not exceed 100 degrees Centigrade. Excessive heat beyond 100 degrees Centigrade can distort the photoresist and ultimately impact the quality of the etched pattern.

A typical etch rate for Gold is 1,200 Angstroms/minute (or 0.12 microns/minute) and 200 Angstroms/minute for photoresist (@ Vbeam = 500 eV and j = 1 mA/cm2 [1]). The etch rate for the photoresist is significant. Parameters such as etch depth, etch angle and aspect ratio, dictate the photoresist thickness requirement. The photoresist thickness has physical limitations by the application process (viscosity and photo resister spinner RPM). In some applications, multiple iterations of applying the photoresist pattern and etching may be required to achieve the desired depth. At least two datum points are required to align the mask when multiple photoresist applications are required to maintain pattern integrity. Side-wall redeposition and trenching can be significant for a large aspect ratio (feature depth/width) greater than 2 [1]. The beam angle of incidence can be adjusted to remove material that has re-deposited to the side-wall. However, it is important to note that this method of removing side-wall redeposition has a diminishing return as the aspect ratio increases.

The Ion Beam is not a significant error contributor to the patterns etched into the substrate. Significant pattern error contributors or variations include:

- Facets or rounding of Photo Resist
- Photoresist side-wall with a positive slope instead of vertical slope
- Photoresist shrinkage caused by improper developing and curing
- Glass mask variations

APPLICATIONS

Traditionally, ion beam etching has been applied to higher value-added devices, which require long operational lifetimes as well as precise performance specifications. These devices include commercial disk drive products, military, and commercial communication components, microelectronic circuits and sensor products for automotive, medical and aerospace applications.

COMMUNICATIONS & MICROWAVE COMPONENTS

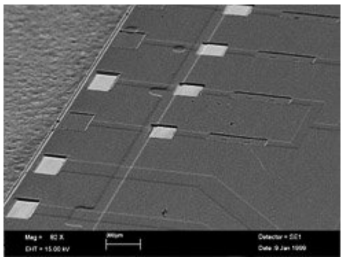


Figure 3: *Microwave Circuit (Neuman SEM)*

Visible signs of how micro-technology has influenced our lives is evident in how fast the cellular phone has transformed from a simple bulky phone to a multi-function business telecommunication hub. Today cellular phones are only fractions of their original size in comparison to the first units released into the market. Not only have they become smaller, they now offer paging, email, phone service and integrated portable computers all in one package.

This level of micro-miniaturization was realized by the application of micro-etching and micro-machining techniques, such as ion beam etching. Ion beam milling has influenced the development of precise and compact components such as the microwave and micro-circuitry shown in **Figure 3**.

BIOMEDICAL COMPONENTS & SENSORS

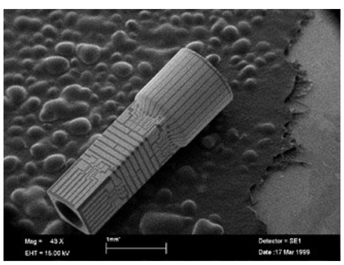


Figure 4: *3D Circuit (Neuman SEM)*

As a result of the application of ion beam etching and other micro-machining technologies, a host of new miniature disposable biomedical products have entered the mainstream medical market. Many of these new biomedical devices are based on thin film metals, polymer, glass and silicon microstructures that are embedded into different assemblies. Examples of these microstructures include electrodes, micro-circuits, nozzles, micro-channels, wells, slots, and arrays of pillar-type structures.

Diagnostic applications utilize both passive and active devices. Passive devices take advantage of physical laws such as capillary flow to transport fluid samples from small wells to a series of pillars or channels that are coated with a reagent that reacts to the fluid. These types of structures are commonly

found on pregnancy and drug detection kits where specialized reagents are used to detect specific drugs in a blood or urine sample. Active devices incorporate both passive and active elements. Active elements are structures that incorporate electrical elements such as micro-circuitry and electrodes. These active devices incorporated with passive elements may form pumping systems, electrode fields as well as capacitive and resistive arrays. **See figure 4** of a micro-sensor array circuit.

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FIBER OPTIC COMPONENTS

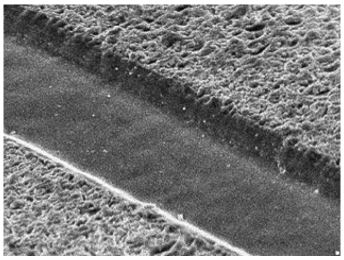

Figure 5: *V-Groove (Neuman SEM)*

Fiber optics will play a key role in the way data is transmitted to and from the office, home and across the world. Major advances in packaging technology have made the installation of fiber networks common in corporations and for transporting large volumes of phone and other telecommunications across oceans.

The most exciting of these developments is the development of Hybrid Optical Chips (HOC). Using a variety of microelectronic fabrication and packaging technologies, fiber optic transmit and receive modules have been reduced down to a level where they can be easily installed in standard PC racks.

The next step in the evolution of these fiber optic devices is controlling the cost of fabrication. Current

methods use standard printed circuit boards and semi-precise molded fiber connectors. These devices have brought the retail price down to the $250 to $400 unit cost. The goal is to break the $200 mark.

Manufacturers targeting the fiber optics communication industry see micro-technology as the solution to reducing costs. Development of ion etched v-grooves in silicon as well as control circuitry for the diode lasers has provided a rapid method of alignment for single mode and multi-mode fibers, **See figure 5**. By making the alignment of fiber to diode lasers simple as well as fast, the resulting costs are significantly reduced. The biggest benefit is the ability to use standard batch ion etching techniques to precisely fabricate the devices.

By integrating, control electronics, circuitry, diode laser and fiber alignment, one can see a process where high-speed manufacturing can take place. This is how affordable devices in volume can penetrate the market.

TRADE-OFF DECISION FACTORS

There are clear and distinctive advantages to ion beam etching. The most evident advantage is the ultimate precision, which is measured as tolerance. Typically a tolerance of 0.1 to 0.3 microns is produced using ion beam etching, whereas chemical etching has a tolerance of approximately 1.5 to 2.5 microns depending on the material and the etchant being used. Another advantage is material selectivity. In most cases, chemical etching is limited to most metals, where ion

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beam etching can cover a wider array of material, including a number of organic and inorganic thin films that can not be etched by chemicals. This provides a designer with more freedom to use less expensive or better performing materials.

These are the simple tradeoffs, but ultimately the bottom line plays a role in the decision process. Clearly, analysis needs to be done to establish the baseline cost differential between the wet and dry etch process technologies. Customer requirements for high density, high precision, high performance as well as low cost will ultimately drive the use of ion beam technology. The reason is simple, micro-miniaturization demands the precision of ion beam technology where chemical etching is a gamble.

CONCLUSION

Ion beam etching is clearly an enabling process technology for precision microdevices and micro-circuitry. As demands for higher density continue, ion beam etching will be the best option for offering quick and reliable prototyping solutions as well as batch production. The trend is evident, high-density packaging is here, ion beam etching provides the solution.

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