Applications of Cold Cathode PIG Ion Source in Lithography

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ABSTRACT

The cold cathode Penning ion source (PIG) of axial type could be modified to produce ion and electron beam with a considerable amount to use it in the lithography process. Lithography is a new applications of ion/electron beam at which one can use the ion/electron beam as a pencil to write and draw on a metal surface. The electron beam takes 1/3 the time needed for ion beam to make good picture. So that with the help of ion/electron beam lithography one can mark tools, parts, instruments, and equipment with names, numbers, designs, trademark or brand name in few seconds. It is an easy process, quick and an inexpensive method. Firstly, operating characteristics of this ion source is studied. Lithography application of ion source with optimum conditions is done. Later, the hardness and the tensile strength is measured and each of them increases with increasing time.

Key Words: Ion Beam / Electron Beam / Lithography.

INTRODUCTION

Lithography is a method for printing and drawing using a stone or a metal plate with a completely smooth surface. The ancient Egyptian man is the first one who used this method to write and draw. Pharaohs recorded their history on their temples and tombs by using lithography on the stones 7000 years ago. In the new history lithography was invented in 1796 by a Bavarian author called Alois Senefelder\(^{(1, 2)}\) as a low cost method for publishing the article works. Now lithography is used to print text or art work on paper or any suitable materials\(^{(3)}\). Lithography is a type of drawing and printing using chemical and physical methods. In the chemical method\(^{(4)}\) the smooth surface is engraved, etched or stippled to make cavities to contain the printing ink. Chemical lithography method uses oils, acids, ink and many chemical reagents to produce an image i.e it can save time and money to produce an image. Lithography uses simple chemical process to create an image. For instance, the positive part of an image is a hydrophobic or water hating substance, while the negative image would be hydrophilic or water loving. Thus, when the plate is introduced to a compatible printing ink and water mixture, the ink will adhere to the positive image and the water will clean the negative one. This allows the flat print plate enabling much longer and more detailed print runs than the older methods. It can be used to print texts or art work onto paper or other suitable materials. The word lithography also refers to photo-lithography, a micro fabrication technique used to make integrated circuits and micro electro mechanical systems. In the physical method\(^{(5)}\), the possible ways to perform optical lithography are extreme UV, X-rays, electron and ion beam projection, which are new tools to obtain good resolution.

Ion Beam Lithography

The ion/or electron beam lithography (I/EBL) is the practice of scanning a focused beam in a patterned fashion across a surface in order to create very small structures such as integrated circuits or other nanostructure. Ion beam lithography has been found to be useful for transferring high fidelity
patterns on three dimensional surfaces \(^{(6)}\). The electron beam lithography has been found to be useful when the exposed surface was covered with a thin film \(^{(7)}\). The focused ion beam lithography scans an ion beam across the surface to form a pattern. The ion beam lines corrode the exposed place down to a desired level below the original surface, while the protected metal remains intact. The ion beam may be used for directly sputtering the surface, or may induce chemical reactions in the exposed top layer (resist). In the case of direct sputtering, re-deposition is a common occurrence, which will affect the final surface profile. In the case of resist exposure, the slowing down of secondary electrons is the bases for forming the final image, which therefore limit the resolution of acceptably printed features, even though the beam spot size can be small. One of the unique features of ion beams is their ability to define features without using resists. So that, of all the particles types used on lithography, ions has the shortest effective wave length, so that they achieved the smallest feature. In ion beam lithography, when ion beam lines passing through the substrate, a photographic image of a substrate is transferred onto a metal surface of the F.C. This process is used by any one who wishes to have an enhanced surface quality to a piece of artwork. So that one can write and draw anything on a metal surface using ion beam. We can say that the ion beam is a new tool to write and draw on a metal surface. The ion beam is extracted, focused and transported to the target. It is necessary to obtain a beam with characteristic as close as possible to the limit of ion optical perfection. This includes high current density and medium energy.

**EXPERIMENTAL**

Figure (1) shows the using apparatus which is a type of PIG ion source designed and made in our lab \(^{(8)}\). PIG ion source can make a magneto-electrically confined plasma discharge in which gross confinement of electrons is provided by an axial magnetic field and an axial electrostatic potential well. Electrons are electro-statically trapped axially and magnetically trapped radially until they collide with the gas atoms and ionize them. The absence of the filament in this source means less power consumed than the most other sources of similar size and capability. This affects longer life time of the source than can be expected from most other sources and less sputtering inside the source which decreases the contamination resulting from the material inside the source. This source produces a wide range of positive ion and electron current in the range of few microamperes up to 1 mA which is a suitable range for some applications such as writing and drawing.

![Fig.(1): Schematic diagram of the Penning ion source (PIG).](image)

The optimum experimental conditions that used for ion / electron lithography are:
$V_{\text{arc}}$ (arc voltage) = 380 V, $I_{\text{arc}}$ (arc current) = 1 A, magnet = 430 Gauss, $P_r = 2.5 \times 10^{-4}$ Torr.

$V_{\text{ext}}$ (extraction voltage) = 5 kV, $I_{\text{ext}}$ (extraction current) = 2 mA, using argon gas.

Figure (2) shows the experimental set up for the lithography process. The ion beam passing through the specimen, the image of the specimen is drowning on the Faraday cup. The time must be sufficient to make the image clear visible but the durability of the image on the metal depends on the content of the material being used, the intensity of the incident beam and the exposure time. This process is used in volume scale to produce posters, maps, books and newspapers.

![Figure 2: Schematic diagram of the specimen](image)

**RESULTS AND DISCUSSION**

Figure (3) shows the extraction characteristics of the ion source, which is the relation between the extraction voltage in (kV) on x-axis, the extracted ion current in ($\mu$A) in the left y-axis and extracted electron current in (mA) in the right y-axis. The relation between the extraction voltage $V_{\text{ex}}^{3/2}$ and the extracted current $I_{\text{ex}}$ is described by Child- Langmiur low which

$$I_{\text{ex}} = \frac{4}{9} \epsilon_0 \pi S^2 (2q/m)^{1/2} V_{\text{ex}}^{3/2}$$  \hspace{1cm} (1)

Where $S = a/d$ is the aspect ratio (the relation between the aperture beam exit (a) and the extraction gap distance (d)). So, for the same ion source the quantity $\frac{4}{9} \epsilon_0 \pi S^2 (2q/m)^{1/2}$ is constant called the perviance of the ion source$^9$. The perviance, $P$, depends on the ion source geometry.

$$I_{\text{ex}} = PV^{3/2}$$  \hspace{1cm} (2)
\[ I/I_e = \left( \frac{m_i}{m_e} \right) \]

But \( m_e \ll m_i \) Then \( I_e \gg I_i \) (3)

Experimentally \( I_e = 8 I_i \) (4)

Figure (3) also shows that the extracted ion/electron current increases with increasing the extraction voltage at different values of the arc current and different values of the electro-magnet surrounding the ion source. The figure also shows that the extracted electron current is 8 times the extracted ion current for the corresponding parameters; i.e. the extracted electron current is very greater than the ion current as shown in equation (4).

A screen is placed in the ion beam path, the ion beam passing through the screen; an image of the screen is drawing on the copper F.C., figure (4) is the screen image. Put a specimen carrying the name of Allah in the pass of the ion beam, the image of the specimen is drawn on a copper F.C shown in Figure (5) At first, the exposes time is half an hour, the picture is not clear as shown in Figure (5-a), when the time increases to an hour and half, the picture is very clear as shown in Figure (5-b). Using an electron beam for half an hour and prose as a F.C. Figure (6) shows a good picture for the specimen. The clear picture using an electron beam takes half an hour but that using an ion beam takes hour and half i.e the electron beam takes 1/3 the time needed with the ion beam to get a clear picture. We can say that the electron beam is faster and economical.

![Graph showing extracted ion and electron currents versus extraction voltage](image)

**Fig.(3):** The extracted beam currents versus extraction voltage for a constant pressure of 6.5 x 10^{-4} mbar of argon. The extracted electron current is plotted to the right Y-axis and is represented by the curve marked with empty circle symbol.
Fig. (4): The screen image.

(5-a) half hour (5-b) hour and half

Fig. (5): The name of Allah is drawn on copper using an ion beam.

Fig. (6): Pross as Faraday cup for writing the name of Allah using an electron beam.
Measurement of the tensile strength and the hardness on the copper specimen were done in the metallurgy dept., NRC, AEA, Egypt. It was found that tensile strength and the hardness on the picture of the name of Allah is different from the surroundings and also different from the references. Each of the tensile strength and the hardness increases with increasing time as shown in the Figures (7) and (8).

Fig. (7): The tensile strength of the specimen

Fig. (8): Hardness of the specimen
CONCLUSION

From this work, it can be deduced the following:

1- It is possible to use ion and electron beam as a pencil to write and draw on any smooth metal surface.
2- High volume lithography is used today to produce posters, maps, books and newspapers.
3- The importance of ion/electron beam lithography increases because of their capability of writing very fine patterns onto the resist layer of the smooth surface in a very short time with good accuracy.
4- Using the electron beam, the picture is very clear in a time shorter than that taken with the use of the ion beam i.e the electron beam is faster and economical than ion beam.
5- The hardness and tensile strength increases with increasing time.
6- Ion / electron beam lithography must be done quickly, efficiently, accuracy and with low cost.

REFERENCES