

# International Conference on Space Optics—ICSO 1997

Toulouse, France

2–4 December 1997

*Edited by George Otrio*



## *Microfabrication of high performance optical diaphragm by plasma ion beam etching technology*

*Agnes Mestreau, Henri Bernardet, Guy Dancoing,  
Xavier Godechot, et al.*



icso proceedings



International Conference on Space Optics — ICSO 1997, edited by Georges Otrio, Proc. of SPIE Vol. 10570,  
1057023 · © 1997 ESA and CNES · CCC code: 0277-786X/18/\$18 · doi: 10.1117/12.2326629

**MICROFABRICATION OF HIGH PERFORMANCE OPTICAL DIAPHRAGM  
BY PLASMA ION BEAM ETCHING TECHNOLOGY  
(USINAGE DES BORDS DE DIAPHRAGME PAR BOMBARDEMENT IONIQUE)**

**Agnès MESTREAU, Henri BERNARDET, Guy DANCOING,  
Xavier GODECHOT, Christian PEZANT, Vincent STENGER ;  
Bernard COUSIN, Pierre ETCHETO, Georges OTRIO.**

*SODERN, 20 avenue Descartes - 94451 Limeil-Brevannes Cedex France ;  
CNES (DGA-TAE/INS'IO), 18 avenue Edouard Belin - 31400 Toulouse France.*

**RESUME** - Une technique de micro-usinage utilisant le bombardement ionique a été mise au point par SODERN pour réduire la section efficace des arêtes des diaphragmes pour des baffles utilisés dans un contexte d'environnement radiatif sévère. Les essais d'usinage ont été réalisés avec des diaphragmes en aluminium sur un dispositif expérimental. L'observation au microscope électronique a permis de constater que le rayon de courbure extrême de l'arête pouvait être rendu inférieur au micron. Les mesures optiques de diffusion ont été effectuées suivant une approche globale et une approche locale. Les résultats obtenus mettent en évidence un gain d'un facteur 2 à 5 par rapport aux performances atteintes avec un usinage et un traitement de surface noir classiques. La sensibilité à la polarisation de la lumière incidente est devenue négligeable.

**ABSTRACT** - A microfabrication technology using a ion beam bombardment device has been developed by SODERN in order to reduce the diaphragm edge cross section for baffles working in a severe radiative environment. The etching tests have been performed on diaphragms made in aluminium alloy on an experimental set-up. The analysis with a scanning electron microscope shows that the extreme edge radius becomes lower than one micron. The optical scattering tests have been performed with a global approach and a local one. The results point out an improvement by a factor 2 to 5 compared to the performances obtained with a black diaphragm manufactured by standard machining and anodised coating. The sensitivity to the polarisation of the incident light becomes negligible.

## **- INTRODUCTION**

Optical baffles are essential components of many optical systems. They offer an effective method for straylight management and they are usually the first components of the straylight chain. They protect optical systems against unwanted light by attenuating the flux and hence govern the signal-to-noise performance of the system. The efficiency of a baffle is directly related to the quality of both the surface coatings and the diaphragm edges. Reducing the direct scattering of the diaphragm edge consists in improving the scattering factor of the diaphragm and refining the thickness of the edge.

The baffle is the most exposed component of an optical sensor in space. In a radiation-enhanced environment, the baffle materials should comply with the radiation hardness specifications. While the standard materials like black paint or anodic oxidation have excellent light absorbing

characteristics, they are not robust enough in radiation-enhanced environment. Moreover, the baffle material should be chosen among the radiation hardened materials like beryllium or carbon. Thus, due to their local efficiency, the ion beam technologies are attractive to the microfabrication of diaphragms for hardened and high performance baffles.

Within this context, a study of the microfabrication of high performance optical diaphragms is supported by the "Direction Generale de l'Armement" DGA and the "Centre National d'Etudes Spatiales" (French space agency) CNES. A new tool is developed to obtain radiation hardened and ultra thin edge of vanes. The technology is applied to aluminium substrate and could be applied to beryllium metal. The rough shape of the diaphragms is obtained with the standard machining tools and the inner edge could be assimilated to a torus with a curvature radius of 15 to 20  $\mu\text{m}$ . The objective of the ion beam etching is to reduce this radius down to 1  $\mu\text{m}$ .

## 2 - FABRICATION PROCESS

### 2.1 - Ion beam etching physical process

The physical process is based on the sputtering of the diaphragm edge with energetic incident ions, which provides a micron-sized etching. The process is similar to the ion beam microtexturing of surface described in reference [Auci 84]. Basically, ions from a plasma source impinge a surface and sputter away atoms from the target. The etching yield is a function of the following parameters: incident ion, ion velocity, incident angle and target atoms (ref. [Cart 68], [Auci 84]). The ions are produced by a magnetron discharge in a cross electrical and magnetic field (ref. [Thor 78]). This particularity allows a low pressure - high voltage discharge. The low pressure environment reduces collisions between the ions and the atoms of the gas contained in the chamber, and allows the ions to keep a high kinetic energy in order to bombard the target. The anode is at the centre of the discharge and the cathode is the surrounding cylinder. A circular slit is made in the cathode in order to extract and accelerate the ions. These ions are projected onto the target which is etched by sputtering. A DC bias is applied between the target and the plasma source to enhance the etching. The target is the inner edge of a diaphragm which is thinned down by the etching. The schematic view of the experimental set-up is presented in Fig. 1.

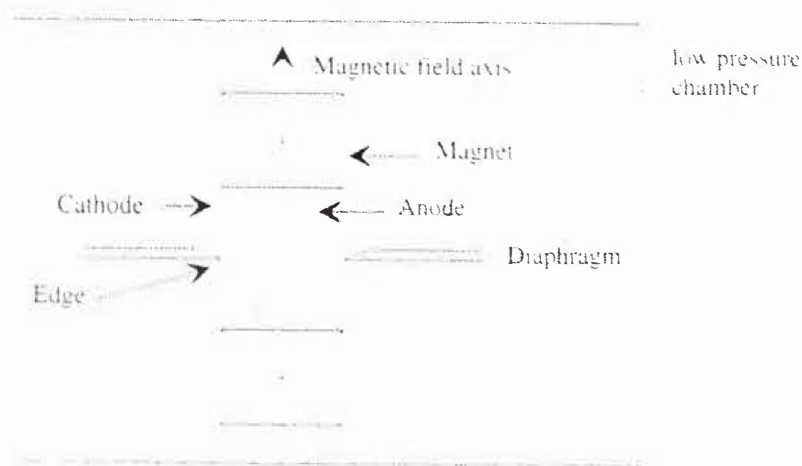


Fig. 1 Schematic view of the edge ion beam etching with magnetron discharge

## 2.2 - Experimental set up

In order to satisfy these requirements, a magnetron configuration (Fig. 2) has been developed. With this device, it was possible to fix an annular Argon plasma of energetic ( $\approx 5$  keV) ions in a vacuum chamber. The edge is placed on a rotating support and is entirely immersed inside the magnetron discharge. It is polarised at 5 kV. The diameter of the magnetron is adjustable to the diameter of the diaphragm to be etched. This allows to etch diaphragms of different sizes. The target rotation insures an homogeneous and continuous etching, and the non-uniformities of discharge and concentricity are finally smoothed. The experimental set-up was designed in order to adjust the concentricity between the magnetron and the diaphragm and the parallelism between the plane of the edge and the plane of the magnetron split. It was adjusted in order to control its thermal drift which could demagnetize the magnet or disturb the rotating motor. It was also designed to avoid or limit the short-circuits between the cathode and the edge of the sample - such phenomenon could lead to microscopic sparks and spoil the edge.

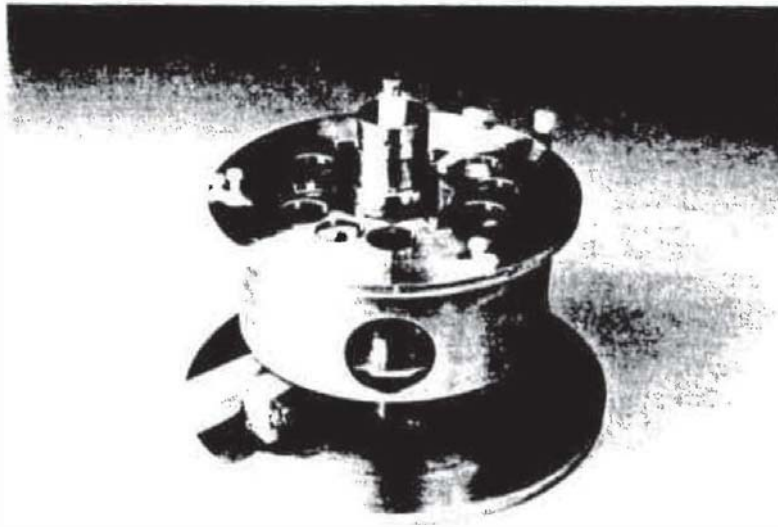


Fig. 2 Photo of the experimental set-up

## 2.3 - Production of diaphragms

The experimental set-up was used for etching diaphragms with an inner diameter of 52 mm. Diaphragms are made of aluminum alloy (6061) and are 1 mm thick. The inner edge of the diaphragm is machined with a bevel of  $30^\circ$ , obtained with a standard machining tool. Its radius of curvature is around 15 to 20  $\mu\text{m}$  (Fig. 3). Four hours are necessary to etch the edge and to reduce the radius down to 1  $\mu\text{m}$  (Fig. 4). The morphology of the edge is analysed with two methods - microscopic cross-section examination with a binocular and global diaphragm analysis with a scanning electron microscope (the dimension represented by the first white dash corresponds to the real dimension written underneath). The benefit of the ion beam etching technology is significant considering the sharpness of the edge - when it is compared to the standard technology.

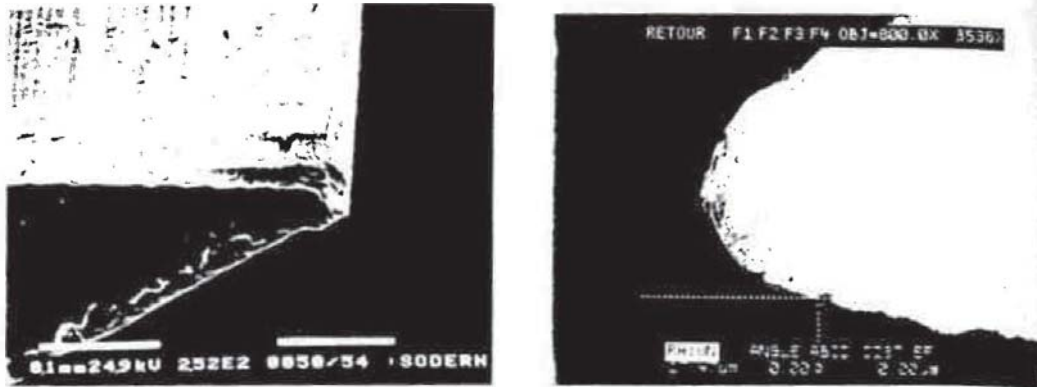


Fig. 3 Photos of the diaphragm before ion beam etching (standard machining tool)  
[scanning electron microscope and cross-section examination]

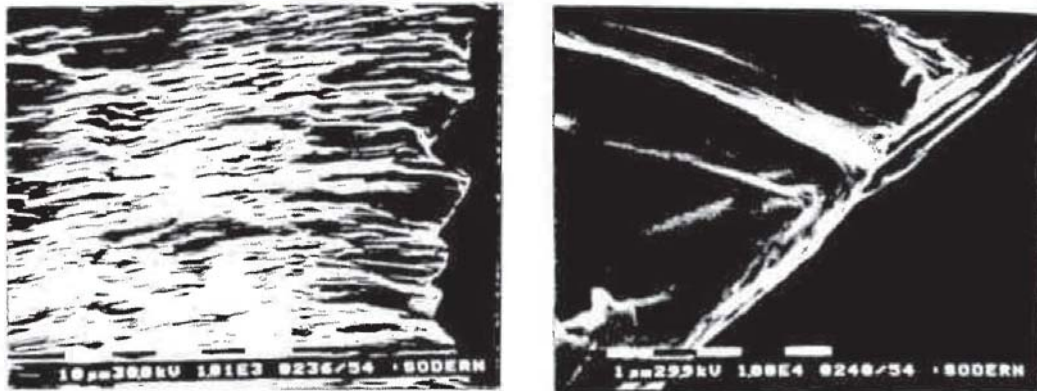


Fig. 4 Photos of the diaphragm after ion beam etching  
[scanning electron microscope]

#### 2.4 - Blackening of the samples

Prior to any optical characterization, the samples are blackened to make the analyses easier. In order to avoid degradation of the edge thickness, a thin black carbon layer was chosen, and was made using a low pressure plasma deposition system

A similar magnetron as the one used for ion beam etching, is horizontally disposed. During operation of the discharge, carbon atoms from the central cathode are sputtered away and condense on the sample. Fig. 5 presents the schematic view of the set-up. The thin carbon layer behaves with interferential properties. Its colour depends on the thickness of the coating. The layer becomes absorbent after a certain thickness and the sample becomes black

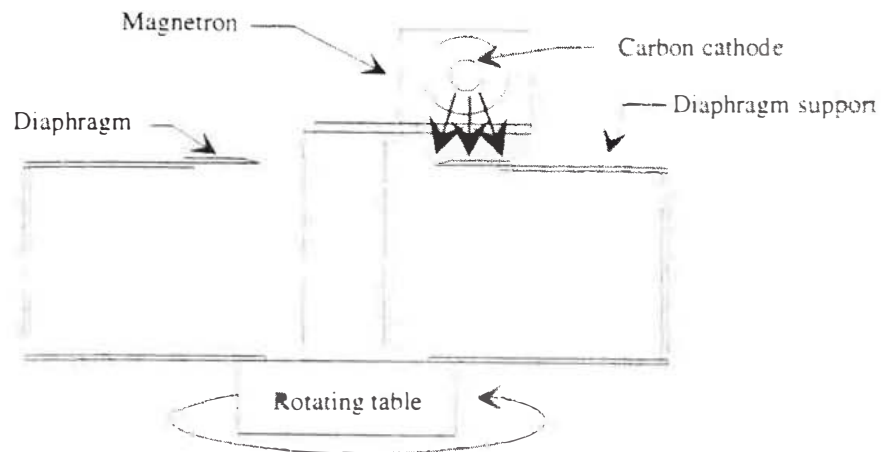


Fig. 5 : Schematic view of the system of the low pressure plasma deposition of a carbon layer

### 3 - OPTICAL CHARACTERIZATION

The technology of ion beam etching improves significantly the thinness of the edge of the diaphragm. Performance in term of scattering should be analysed. Four diaphragms are compared. They are referenced with the following names :

- ◆ "standard edge" : manufactured by standard machining,
- ◆ "standard anodised edge" : manufactured by standard machining and blackened by anodic oxidation,
- ◆ "ionic etched edge" : manufactured by standard machining and are refined by ion beam etching,
- ◆ "ionic etched black edge" : manufactured by standard machining and are refined by ion beam etching, and coated with the thin carbon layer.

In order to characterize the scattering, two different types of tests have been performed on the diaphragms. The first tests consist of measuring the scattering from the complete edge which is entirely illuminated by a polychromatic parallel beam (white light). They are performed on the SODERN straylight PST bench. The second tests characterize the scattering from a section of the edge illuminated by a monochromatic (514 nm) light. They are carried out on the CNES straylight BRDF set-up. The results obtained with the two approaches correspond to two different parameters of the scattering, they are not directly comparable but they are complementary and allow a good knowledge of the behaviour of the edge.

#### 3.1 Polychromatic (white) scattering from the complete diaphragm

Fig 6 presents the schematic view of the PST set-up used for the tests of the complete edge which is entirely illuminated. The incident beam, coming from a filament lamp (400 W power), is collimated and reaches the diaphragm with a normal incidence. The detector, a photomultiplier, is placed at 800 mm from the sample and moves around the sample. The total field of view of the detector is restricted to  $6^\circ$  in order both to cover a zone slightly larger than the edge and to limit the detection of any straylight coming from the environment. Different protective screens and light-traps are well-placed for reducing the unwanted straylight. The four samples, previously described, are measured and the results are displayed in Fig. 7

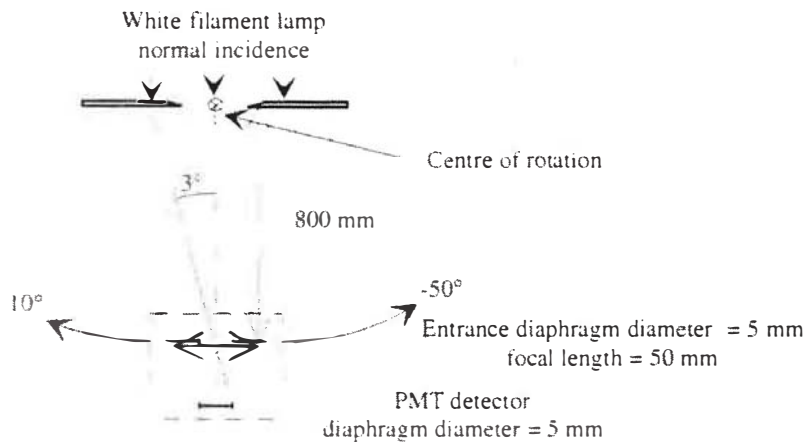


Fig. 6 Tests of the scattering of the complete edge

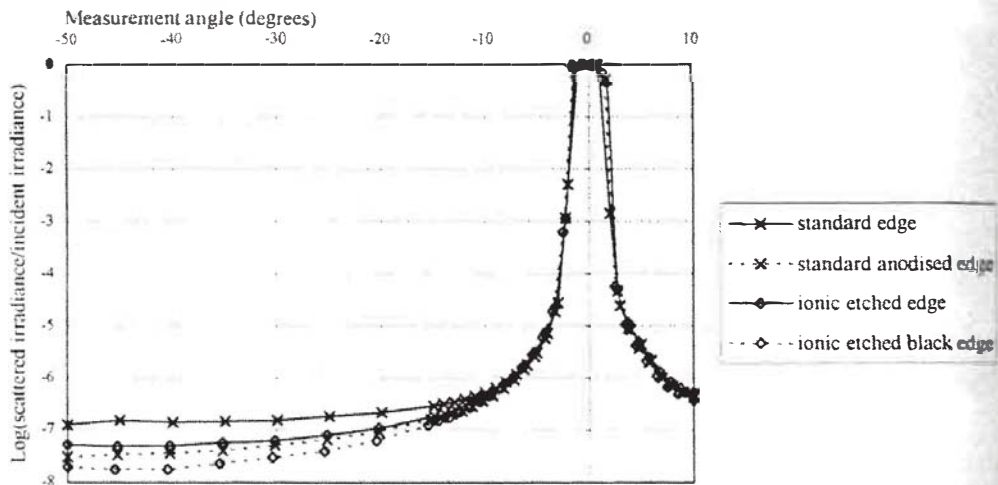


Fig. 7 : Scattering results of the four samples

The homogeneity of the etching is controlled by verifying the independence of the results versus the rotation of the sample around its axis. The central peak corresponds to the incident beam passing through the diaphragm. Different remarks stand out from Fig. 7

- ◆ the anodic oxidation of a standard edge (manufactured by machining) reduces the scattering by a factor of 5,
- ◆ the ion beam etching decreases by a factor of 4 the scattering of a non blackened edge (comparison between the two uncoated samples),
- ◆ the ionic etched black edge scatters less than half as much light as the standard anodised edge,
- ◆ the scattering of the ionic etched edge is equivalent to the scattering of a standard anodised edge. this is the target for the baffles in radiation-enhanced environment

The effect of the edge scattering is difficult to discriminate from the scattering coming from the surface closed to the diaphragm edge. The ratio between the scattering of the standard anodised edge and the ionic etched black edge can be expected to be greater

3.2 - Monochromatic scattering from a section of the edge

The same four samples were tested on the BRDF bench. Fig. 8 presents a schematic view of the bench. The edge is illuminated by a 3 mm diameter Argon laser beam at 514 nm whose polarizations P and S are selected. A silicon detector is mounted on the extremity of an one metre handle, pivoting around the sample. A lens with a 10 mm entrance diaphragm gives an image of the sample on the detector, which detects a 30 mm diameter area in the sample plane. For the weak flux, synchronous detection measurements complete direct measurements. The unwanted straylight coming from the environment and the diaphragm is reduced as much as possible. The measurements of the uncoated samples are so much disturbed by this straylight that they are unusable, so only the results of the two black samples are exploited.

Fig. 9 shows the ESDF ("Edge scattering distribution function") which corresponds to the scattered irradiance per solid angle and divided by the incident irradiance. The results, with the negative angles, correspond to the diaphragm side, and the results with the positive angles correspond to the open side area.

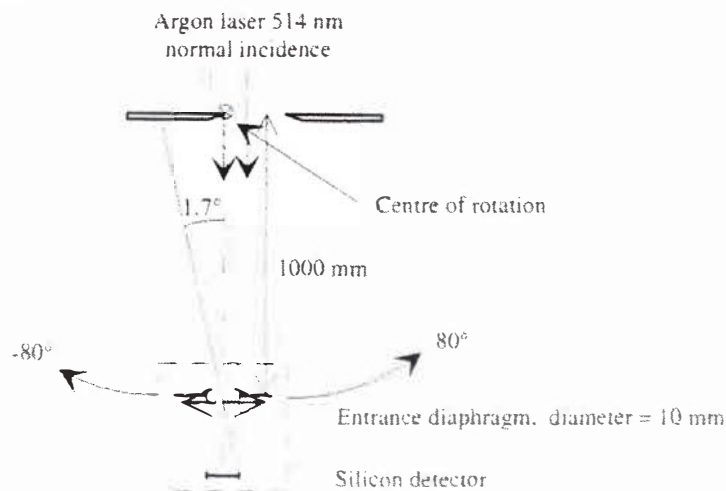


Fig. 8 Monochromatic tests of a section of the edge

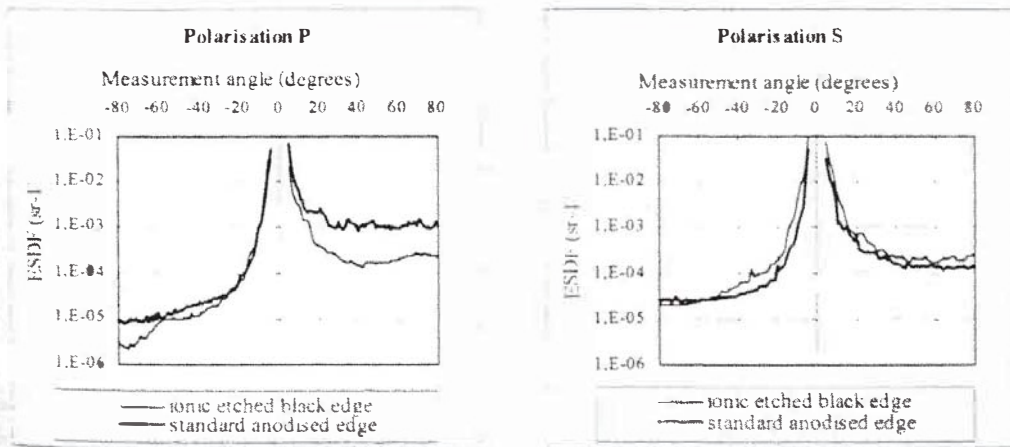


Fig. 9 Scattering of an edge section for the polarisations P and S of the incident beam



The following remarks stand out

- ♦ the scattering of ionic etched black edge is insensitive to the polarization of the incident beam, contrary to the scattering of the standard anodised edge,
- ♦ in S polarization, the ionic etched black edge scatters with the same level compared with the standard anodised edge, in P polarization, it scatters 10 times less, thus, for a unpolarized light, the ionic etched black edge scatters five times less than the standard anodised edge

#### 4 - CONCLUSION

Tests of ion beam etching were performed by using an experimental set-up with diaphragms made of aluminium alloy (6061). The morphologic analysis allows to notice that the radius of curvature of the inner edge of the diaphragm goes down below  $1 \mu\text{m}$ . Optical scattering tests were performed on four different diaphragms following a global approach and a local approach. They lead to the same conclusion: the diaphragm that have been refined by a ion bombardment and coated with a carbon layer scatters less than the standard diaphragm with anodic oxidation. The scattering from a complete diaphragm, illuminated by a white light, is at least half less for the diaphragm obtained by ion beam etching and coated with a carbon layer, compared with the standard anodised diaphragm. It becomes to five times less when only a small section of the edge is illuminated by a monochromatic light at 514 nm. Moreover, the monochromatic tests show that the sensitivity to the polarisation of the incident light becomes negligible for an edge etched by ion beam bombardment. This effect is interesting for a use of diaphragms in a monochromatic light.

This work shows that the contribution of the ion beam technology is noteworthy. It demonstrates that both morphology and scattering properties of diaphragm edges can be improved. The ion beam process may be applied to beryllium so as to obtain high performance radiation hardened diaphragms

#### REFERENCES

- [Cart 68] G. Carter, J. S. Colligon "Ion bombardment of solids", *Heinemann Education Books Ltd*, London, 1968
- [Auci 84] O. Auciello, R. Kelly "Ion bombardment modification of surfaces, fundamentals and applications", *Elsevier*, 1984
- [Thor 78] J. A. Thornton "Magnetron sputtering: basic physics and application to cylindrical magnetrons", *Journal of Vacuum Technology* 15, 171, 1978