The Ion Beam Figuring Facility at CSL

Introduction

Ion beam figuring was developed in the 70's with the apparition of a Kaufman type ion gun. This technique, also called ion polishing, is an alternative to standard methods of polishing which can be long and expensive. Erosion of the material under ion bombardment is a stable and controlable process. The physical phenomenon by which material is removed is called “sputtering”. Ion figuring is realised in vacuum. The process consists to raster an ion beam with appropriate computed velocities across the workpiece to improve its surface figure. By this way the undesirable long spatial wavelength defects are etched by ions. It's a deterministic, non-contact technique.

The facility and its metrology

CSL built in the 90's a 1.5 m3 ion beam figuring facility. This facility is placed in a class 10 000 clean room. It allows polishing optics up to 20 cm diameter. The ion gun is a 3 cm Hollow Cathode Ion Beam Source manufactured by ION TECH. An electron gun points at the beam and the workpiece to neutralise the global charge. Furthermore, the electrons reduce spreading of the ion beam due to electric repulsion and avoid repulsion of the ion beam on dielectric targets. The ion beam gun has to scan the workpiece at normal incidence and constant distance. For this, the ion gun movements are controlled by software for x,y translation and θ_x, θ_y rotation. The z translation is performed by the workpiece mount. The mobility on x,y translation axes is about 30 cm and maximum angle for the rotation axes is 45°. Stepper motors are used and allow a position precision of 1 µm. An automaton (not visible on this photo) controls pumping and venting operations. A pressure of 10^{-6} mbar can be reached with the primary (63 m^3/h) and the turbomolecular pump (1500 l/s).

Some precision instruments are attached to the facility or easily available for it:

- Interferometer Zygo Mark IV:

The output of this interferometer is a collimated beam, 10 cm broad. Flat and spherical (from 0.75 to 7.5 f-number) references are available for figure measurement of optics before and after ion polishing. It can also be used to measure the ion beam removal profile.

- Interferometer MiniFizz:

This more recent interferometer is similar to the Zygo interferometer. Moreover its optical axis is vertical in usual configuration.

- Profilometer Wyko:

This interferometric profilometer can measure a very large range of surfaces (from 0.1 nm rms to 20 nm rms). This profilometer is used for ion etching depth measurements and for studies on roughness evolution under ion bombardment.

- Thermographic camera:

The model is Thermovision 900 LW AGEMA. This camera allows to measure without contacts (thus without damages) the surface temperature of the optics during ion polishing.

Ion beam figuring process

The surface figure of the optic is measured with an interferometer before polishing. The phase map is transferred to a computer where the dwell times are computed. This computation requires also the knowledge of the ion beam removal function. Figure 1 shows a typical ion beam removal function on glass for some usual parameters with a 3 cm grid. The points results from etching depth measurements with an interferometric profilometer. The continuous line shows the mathematical function (here a gaussian) used for dwell times computation. Smaller grids can be placed on the ion gun (1 cm) to make the beam profile thinner and therefore to eliminate defaults with greater spatial frequencies.

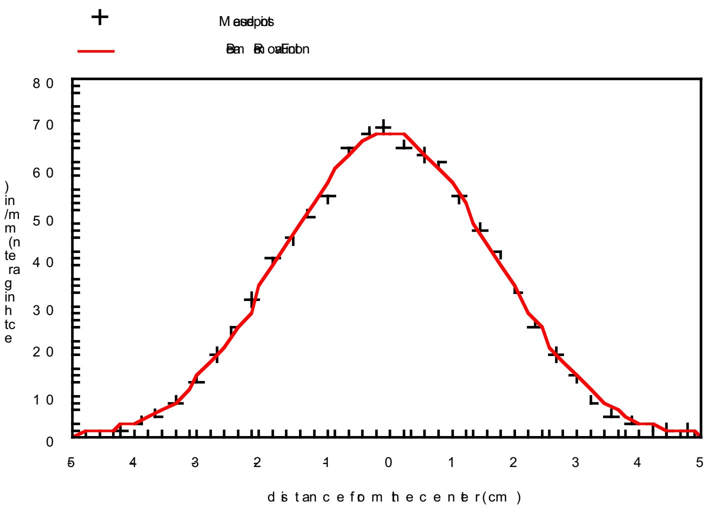

figure 1. 2D plot of the ion beam removal profile.

If d(x,y) is the height of material to remove, h(x,y) is the beam removal function and t(x,y) is the time that the beam is directed at point (x,y), t(x,y) can be found by deconvolution of d(x,y) with h(x,y).

Mathematical operations are realised in Fourier space to reduce the calculation time. D(kx, ky) and H(kx, ky) are the Fourier transform of d(x,y) and h(x,y) respectively. The simple following relation allows to compute t(x,y) :

$$t(x, y) = F^{-1}\left(\frac{D(k_x, k_y)}{H(k_x, k_y)}\right)$$

where F^{-1} is the inverse Fourier Transform. Filters are obviously necessary to prevent instability of the deconvolution process.
The dwell times are computed on a grid of 1024 x 1024 points. Figure 2 shows a 3D dwell times map where the height of the surface represents the time that the ion gun has to stay at each position.

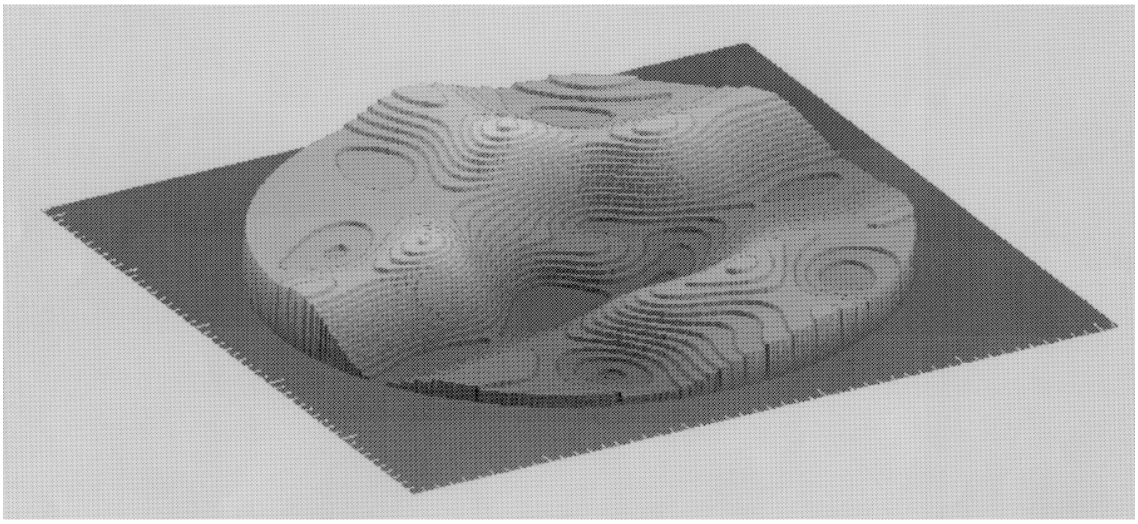

Figure 2. Dwell times map

From the same dwell times map, two types of scan are available on the ion gun driver software : a linear scan and a spiral scan (see figure 3).

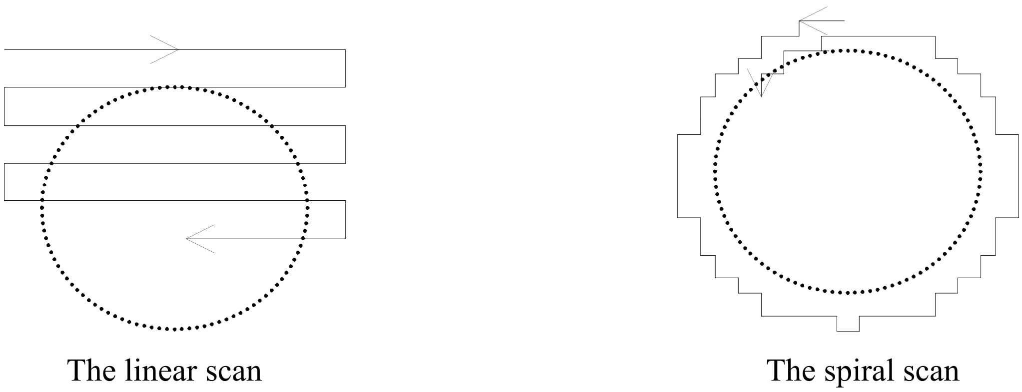

Figure 3. The two possible ion gun paths.

With this technique, the initial rms surface figure (λ/10 – λ/50 rms) is improved at least by a factor 3 in one process (without interruption). It takes a few hours to polish a 10 cm broad mirror if only the ion process is considered (without interferometric measurements, computing, pumping and handling operations). Continuous control of the beam parameters during the polishing process is ensured by the linking of the ion beam power and the ion gun driver software. A thermal treatment is sometimes necessary for some materials if the temperatures involved during ion beam process were too high.

Research and development on the CSL facility

In the last years, some specific studies had been performed on different topics :

- Temperature measurements (with thermocouples and thermographic camera) of the optical surface during ion figuring.
- Algorithm analysis for deconvolution process.
- Study on roughness evolution under ion bombardment on some materials (BK7, Zerodur, Electroless Nickel on Aluminium, …).
- …

Current works on the ion beam facility focus on :

- Development of the ion gun driver software.
- Study on figure distorsions of some glasses due to high thermal gradients.
- Development of software tools for easier and faster process analysis.
- Polishing of some new materials such as SiC
- High removal rate ion beam figuring
- Exotic optics figuring
- …

Industrial Ion Beam Figuring Facility

Currently, an industrial facility, based on this prototype facility, is built in collaboration with a local company. This new facility will be able to figure optics up to 1.2 meter diameter.

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