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David Garzella, Marie-Emmanuelle Couprie, Michel Billardon, "UV-VUV mirrors for storage ring FELs: present performances and requirements," Proc. SPIE 2776, Developments in Optical Component Coatings, (19 August 1996); doi: 10.1117/12.246841

Event: Optical Instrumentation and Systems Design, 1996, Glasgow, United Kingdom

UV-VUV Mirrors for Storage Ring FELs: present performances and requirements.

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ABSTRACT

Storage ring FELs (SRFELs) recently demonstrated to be useful coherent light sources for applications in several branches of scientific research. In particular, the Super ACO SRFEL provided UV light at 350 nm for successful operations in a time resolved fluorescence experiment on a biological molecule and in the first two colour experiment combining synchrotron radiation and FEL light. Up to now, SRFELs are characterised by a relatively low gain and hence, great care must be invested on the choice of optical cavity mirrors.
In this paper we relate the several characterizations performed on different set of mirrors and the obtained results.

1. INTRODUCTION

Free Electron Lasers (FEL) are relatively new sources for producting coherent radiation ranging from far Infrared (FIR) to UltraViolet (UV)[1]. Their specificity comes from being continuous tunable sources all over this spectral range, featuring a high average power (from mW to several Watts), high repetition rate (in the MHz range) and short pulses (few tens of picoseconds). Most improvements in the FEL field have been performed for LINAC-driven devices, where emitted radiation ranges from near to far Infrared. Here the extremely high laser gain (up to 400 %) allows the use of relatively simple resonators and of intracavity devices for extracting considerable amounts of radiation for user application.

On the contrary, Storage Ring FELs (SRFELs), which are mostly used for Visible-UV experiments, exhibit low gains (up to a few percent) and are then limited in their operation by the existence of appropriate optics. In this framework, the Super ACO UV SRFEL is one of the very few operating FEL experiments in the spectral region around 350 nm[2]. Recently, since the first user experiment performed using the FEL light[3], our efforts have been concentrated on the improvements of the FEL source characteristics. The studies accomplished during the last two years allowed us to reach some important results :
1) design and realization of a longitudinal feedback system leading to a more stable laser, with reduced jittering, intensity fluctuations and spectral drift .
2) operation of the laser with a high level of current stored in two bunches (110 mA), even in presence of synchrotron coherent oscillations, with an increased output power (100 mW in the best conditions), and a longer operation time between two injections.
3) First two-colour experiment coupling the FEL light and Synchrotron Radiation : a study of the Surface PhotoVoltage effect (SPV) at the semiconductor/metal interface [4].

Parallel to these studies and results, a main part of our research is devoted to the characterization and the improvement of the optical resonators features, in order to reduce the total losses of the optical cavity and to keep them under the threshold level as far as possible in the time. in this work we want to point out all the difficulties for obtaining a normal operation of the mirrors for this kind of devices, present a state of the art of the existing mirrors for UV FEL operation and some possible solutions for improving these features.

2. SYNCHROTRON RADIATION PRODUCTION

2.1 Spectrum

The SRFEL emission is the result of the interaction between electrons circulating as bunches in the ring and the synchrotron radiation already emitted by them passing through a magnetic device called undulator or wiggler [5]and then stored in an optical cavity. This interaction leads to an amplification of the coherent part of

 0-8194-2161-8/96/$6.00

the emission, then to a laser effect. Here we are interested to the nature of the entire radiation, hitting the mirrors of the optical cavity. Synchrotron radiation emitted by an undulator on axis has a broadband spectrum extending towards X- rays, characterized by a series of even hamonics of the fundamental wavelength $\lambda = \frac{\lambda_0}{2n\gamma^2}\left(1+\frac{K^2}{2}\right)$, where n is the harmonics order, γ is the relativistic energy-to-rest mass ratio of the electron, λ_0 is the spatial period of the undulator and K is a parameter dealing with the deflection force of the magnetic field of the undulator. All the emitted radiation is parted on several harmonics, and even if the fundamental wavelength is the most intense, higher order harmonics show a high number of photons, as we can see in fig. 1. As we will see later, this leads to a high interaction probability with the mirror surface, volume and environment.

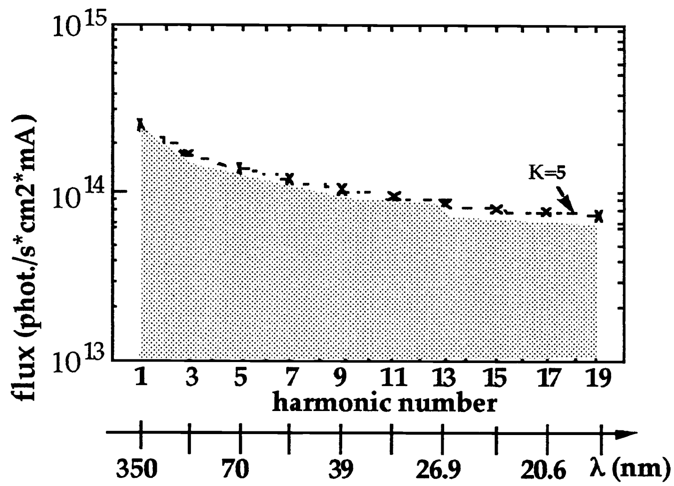


Fig. 1 Synchrotron Radiation Spectrum emitted by the Super ACO FEL undulator.
The hatched zone denotes the total number of photons hitting on the mirror.
Spectrum continues on the right edge

2.2 Power

The total power generated by the undulator radiation is given by :

$$P(W) = 7.28 * E^2(GeV) * N * I(A) * \frac{K^2}{\lambda_0(cm)} \tag{1}$$

with I the average current. The power increases with higher deflection parameters, longer undulators and stored beam current and energies. A typical value for the FEL undulator emitted power is about 22 Watts for a total stored current of 100 mA. This power (and a part of the FEL one) is totally absorbed by the front mirror, principally concentrated in the center. This leads to a rapid increase of the temperature and to the creation of a thermal gradient from the center to the borderline of the mirrors. Indeed, the more the power, the more the photons in the X rays band interacting with the mirror. It then has to be taken into account, especially for the next generation of SRFELs where higher energies, thus power levels, are expected.

2.3 Critical Environnement

The mirrors of the FEL optical cavity are placed under ultra high vacuum, in experimental chambers having a total pressure of about 10^{-9}-10^{-8} torr. Even under these extreme conditions, residual gases, especially of organic nature (e.g cleaning products, particles outgassed by the vacuum chamber walls and holders) are still present, as well as residual quantities of water and hydrogen. The most part of this residuals is expected to interact with the XUV photons, leading to break the bondings in order to form non negligible amounts of carbon. In fig. 2 we can see an example of the partial pressures of the substances present close to the cavity mirror, as detected by a sensitive mass spectrometer quadrupole.

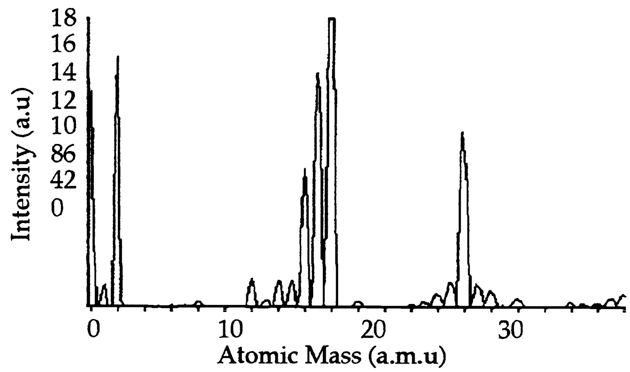


Fig. 2 Mass spectrum effectued on the Super ACO FEL experimental chamber.
Hydrogen, Water and hydrocarbures are the most intense peaks

3. SUPER ACO FEL

The Super ACO FEL is presently operating with a storage ring energy of 800 MeV, allowing, by using a K value of about 5, to operate the laser at a central wavelength of 350 nm. The optical cavity is 18 meters long and it is composed by two spherical mirrors in a quasi confocal configuration, with a diameter of 25 mm. The main feature which determines the choice of the other parameters of the cavity is the laser gain G. This can be expressed by a fairly complicated formula reported in earlier works[6], which results are summarized in a qualitative manner as follows:

-G decreases with the increase of the positron energy and for shorter wavelengths

-G increases with electronic density of the bunch, the undulator length and the filling factor term, defined as the bunch electron-to-stored photon transversal and longitudinal dimensions ratio.

3.1 Optical Cavity Geometry

The Super ACO storage ring being not previously dedicated to FEL experiments, his parameters are not optimized for the obtention of high gain values . At the moment the nominal value obtained by machine experimental parameters is about 2.5 %. This nominal value does not take into account the behaviour of the spontaneous emission mode, from which is strongly dependent. Indeed, an investigation detailed in previous works[7], based on the propagation of gaussian beams[8] shows that, as the spontaneous mode is not a proper mode of the cavity, the waist of the mode and its position with respect to a reference (the distance from one mirror, for example) change for each pass, both oscillating around an average value. Such a behaviour is shown in fig. 3, taken from a simulation including Super ACO parameters. Hence, according to this behaviour, one can imagine that the filling factor term behaves at the same time thus, in order to evaluate the effective gain, one has to take into account this variation. The startup gain can then be evaluated by lowering the nominal one by a proportional factor.

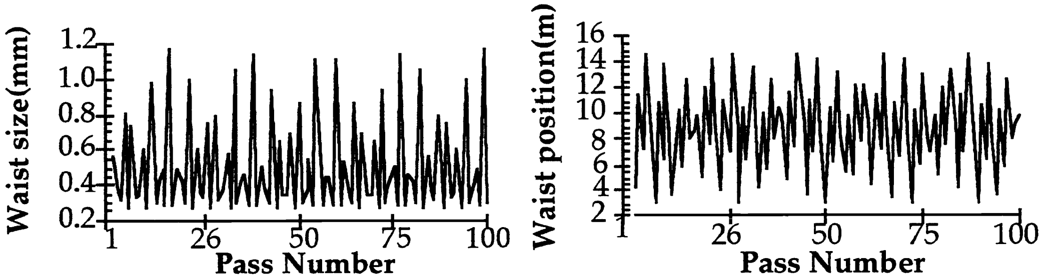


Fig. 3 Simulation showing the variation of the waist size and position during a multipass evolution in the Super ACO FEL 18 meters optical cavity. Center of the cavity is at 9 meters.

Consequently, through the same investigation, the optical cavity geometry must be adapted with a "mode matching" for the spontaneous emission structure. A calculation involving the Super ACO parameters, already presented[7], shows that the optimum of the startup gain is very close to the stability limit of the optical cavity, and strict tolerances of about 1-2 % are requested for the radius of curvature of the mirrors.

3.2 Mirrors

The low gain of the Super ACO FEL has a first consequence dealing with the best performances expected in term of reflectivity of the mirrors for this wavelength range. At normal incidence, metals like Ag, Au or Al exhibit reflectivities ranging between 85 and 95 %,preventing their utilisation. As a consequence, at the moment, the solution is given by the use of high reflectivity dielectric multilayers mirrors. Even with this solution total losses, which we can express for a single mirror by the relation $P = 1 - R = A + D + T$, where P are the losses and each term in the right hand of the equation is a phenomenon responsible of losses in the mirrors (A is the absorption of coatings, D are the losses due to the scattering of the light by a not perfectly smooth surface and finally T is the transmission of the mirror), the problem is not completely overcome, because of the lack of transparent materials. In this framework, both substrates before coating and mirrors after coating are characterized for all the contributions to losses. Moreover, it is important to monitorize the behaviour of the several contributions under irradiation, because of the two-folded need of preventing the degradation of the mirrors and to understand the reasons for this degradation.

a) Total Losses

Measurements of the total losses are performed in LURE employing the phase shift method developped by Herbelin[9]. An Ar^+ laser allows the measurements at 350, 300 and 275 nm. Losses are evaluated with a relative accuracy of about 1 % for losses between 0.1 and 1%.

b) Transmission

The transmission of the mirror is the only term we can choice. It represents a compromise between the will of a high extracted power and a large bandwidth with the need of low losses. According to the gain, T is chosen between 5×10^{-4} et 1×10^{-3} . Optical density measurements are systematically performed with a spectrometer CARY.

c) Scattering

It is well known that a roughened surface scatters the light according to a formula which depends on the spatial frequency spectrum of the roughness and on the illuminating wavelength. One of the consequences of this relation is the increase of scatter losses for the shortest wavelengths (UV and X-rays). Attempts have been made in order to give a scaling law and a criterion to relate precisely the roughness of a substrate or a mirror to his scatter losses. Difficulties arise from the non equivalent values given by different methods employed to measure roughness : mechanical (profilometer) or optical (Zygo, STM, interferential methods) which do not span the same spatial frequency; and by the lack of measurements of Total Integrated Scattering (TIS) in the near UV region. With the collaboration of the group led by C. Boccara at ESPCI, roughness of sapphire and Silica susbstrates and coated mirrors is measured by interferential microscopy[10] in order to obtain a correlation between roughnesses before and after coating and between roughness and total acquired losses. Recently, another collaboration with the optics and thin film laboratory of the ENSPM in Marseille led by C. Amra, allows us to measure directly TIS on substrates and mirrors, in order to find firstly a criterion in the choice of good substrates.

d)Absorption and Reflectivity

Absorption, through the extinction coefficient k, is the other optical property which characterizes a material, together with his refractive index n. The optical properties are strictly related to the spectral topical properties of materials, but also to their conformational state and, in the case of multilayers filters, to the deposition technique of the layers.

Recently, a bench for absorption measurements by "Mirage effect"[11] has been installed in LURE, in collaboration with ESPCI. It utilizes the same Ar^+ laser of the total losses measurements, and exhibitx a sensitivity of about 10 ppm, which is largely enough for our purposes.

4. DEGRADATION

Once the mirrors are characterized, the best couple is inserted in the optical cavity under vacuum. Losses are then measured "In Situ" by the cavity decay time method, using the detection of the stored optical emission by the undulator. This kind of monitoring is necessary because mirrors, especially the front one which receive the total radiation from the undulator, undergo a degradation of their geometrical and optical characteristics due to the power and the specrum of synchrotron radiation already discussed.

4.1 Thermal effects

The considerable amounts of power hitting the front mirror and almost totally absorbed lead to the heating of it. This phenomenon is partially overcome by the use of sapphire substrates for the front mirrors because of the better thermal conductivity, while rear mirrors have silica substrates. These materials, either in bulk structure or as multilayers, are totally absorbant below 1500 Å.

Without any care, even a dramatic destruction of the mirror layers can occur, as happened for example for the ACO SRFEL mirrors exposed to the Super-ACO undulator synchrotron radiation (see fig.4). This can be easily predicted with a simple model.

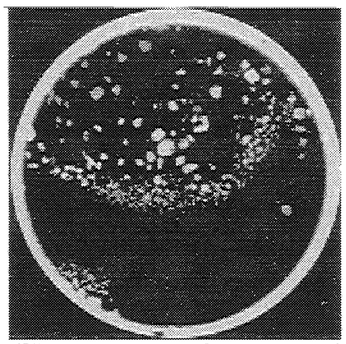


Fig. 4 surface of a FEL mirror coated on silica after exposure to the undulator emission at a high current level

For this, the spontaneous power has to be compared to the laser absorbed power $P_a = P_t * A/T$ (P_t being the transmitted power). It is generally low (<W), nevertheless, the recent 110 mA operation of the Super-ACO FEL, corresponding to asynchrotron power of about 20 W and leading to 0.1 W of transmitted power through one mirror, implies 1 W of absorbed power and an intracavity average power of 200 Watt hitting on both mirrors. Sapphire substrates employed on the Super-ACO FEL could allow the laser oscillation up to this value without destruction. Neverthess, a thermal equilibrium has to be reached (lasting 5 to 30 mn) when the shutter of the beam-line is opened, the undulator power can induce some transient and local mechanical modifications on the mirror[6]. The transient characteristics of these modifications lead to a sequence of laser modes : high order modes resonant with a TEM_{00} or TEM_{01} mode (see fig.5).

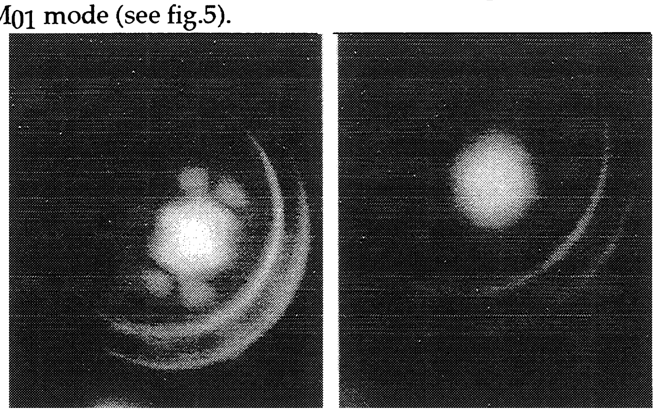


Fig 5 Left: Transient modes resonant with the TEM_{00} during the heating of the mirror right: Once the thermal equilibrium is achieved, only TEM_{00} is present.

This results from a small modification of the radius of curvature leading to resonant transverse modes. The mode TEM_{nm} of phase: $\Phi_{nm} = \frac{4\pi d}{\lambda} - 4(m+n+1) * Arctg\sqrt{\frac{d}{2R_c - d}}$ can be resonant with another mode if their phase difference is a multiple of 2π. Resonant TEM_{nm} with the TEM_{00} mode occur for $tg\left(p\pi/2(m+n)\right) = \left(2/2R_c - d\right)^{0.5}$; with the TEM_{01} mode occur for $tg\left(p\pi/2(m+n-1)\right) = \left(2/2R_c - d\right)^{0.5}$. For example, TEM_{00} and TEM_{04} (resp. TEM_{32}) can be resonant for R_c=10.55 (resp. 9.95) etc... in the Super-ACO case where generally Rc=10m.

The heating of the layers induced by an absorbed power have been tested on top table, using a laser source and an absorbant material deposited on the mirror and measuring the temperature via a thermocouple[12]. High thermal conductivity materials are a solution to reduce both the equilibrium temperature and the equilibrium time without considering the mirror cooling because of the possible mechanical vibrations. But generally better conductivities mean higher thermal expansion coefficients, and more important surface modifications. In addition, a good thermal contact between the mirror and its metallic holder has to be insured, in a compromise with the mechanical characteristics of the mirrors, because a rigid contact with the holder can lead to a mechanical deformation of the mirror, with the appearance of aberrations on the optical image with consequent additional losses in the cavity. Then, the holder system should guarantee both a good thermal and elastic contact. For transparent susbstrates, the limited choice leads to sapphire, with a thermal conductibility of 27 W/(K·m) compared to 1.3 for silica. Otherwise, metallic susbtrates can also be used, with a hole coupling extraction. The dielectric mirrors absorb the largest part of this emission. Because of their relatively low thermal conductivity, their temperature is enhanced until an equilibrium point and this phenomenon changes locally the curvature radius, then the proper modes of the cavity[7]. Recently an "in situ" temperature detection system has been developped at Super ACO, which provides a direct evaluation of the temperature of the mirrors by optical methods[7](fig. 6).

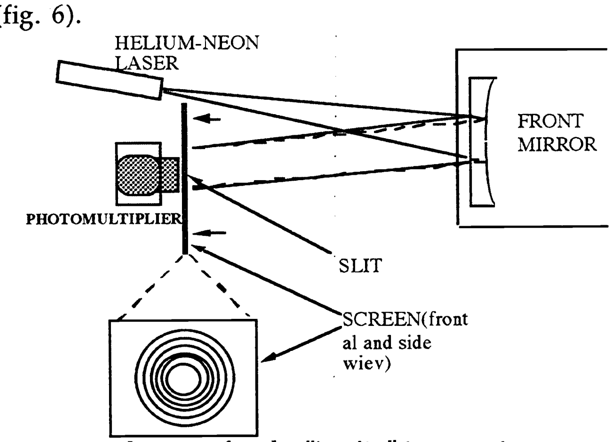


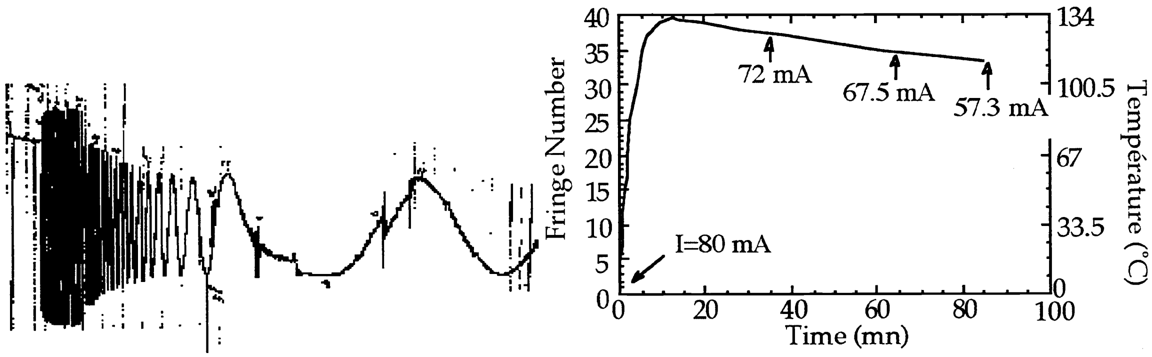
Fig 6 Experimental set-up for the "in situ" temperature measurement.

The optical beam of an Helium-Neon laser is sent onto the rear side of the front mirror. This produces an inteference pattern with a circular symmetry on the plane. The phase difference φ of the fringes is directly related to the thickness of the mirror by the following relation

$$\varphi \cong \frac{4\pi n l}{\lambda} \qquad (2)$$

where n is the refraction index of substrate material and l the thickness. Then, one fringe is selected by a slit and detected with a photomultiplier. This system can detect a fringe displacement related to a local deformation and the variation of the temperature of the mirror induced by radiation. The experimental conditions were the normal ones for a FEL shift, that is to say a deflection parameter K=5, positron energy E=

800 MeV, synchrotron radiation emission centered on the fundamental wavelength λ =350 nm. The total synchrotron radiation power hitting on the front face of the mirror was about 22 watts, almost concentrated on the center. Fig.7 a) and b) shows the registered fringe displacement and the corresponding temperature of the sapphire substrate as a function of time. The substrate of the mirror involved in the experiment is made of sapphire and we observed that the results compared with table-top measurements[12], show a bad thermal contact between the mirror and the metallic holder. Besides it allows to estimate the mirror deformation induced locally by the synchrotron radiation.



The variation of thickness is deduced from (2) according to

$$\Delta\varphi = \frac{2\pi}{\lambda}(2n\Delta l + 2l\Delta n), \quad \Delta n = \frac{dn}{dT}T, \quad \Delta l = l\left[\alpha T + \beta T^2\right] \qquad (3)$$

where α and β are the thermal expansion coefficients and $\frac{dn}{dT}$ is the variation of refractive index with temperature. In the case of the sapphire substrate λ =6328 Å, n =1.78, l =4 mm α =4.53 10^{-6}, β =1.1 10^{-8} and $\frac{dn}{dT}$ =1.3 10^{-5}. Assuming the mirror as a parabolic surface near the minimum $y = \frac{x^2}{2R}$, and considering a radius of curvature of about 10 m and a surface diameter of 25 mm as in the Super ACO case, the observed deformation values, 3.1 μ for 134 °C and 3.4 μ for 160 °C, correspond to changes of the radius of curvature of about twice. This means that the optical cavity geometry changes very rapidly, and the actual gain of the laser is reduced during the whole FEL operation.

4.2 Induced Absorption

One of the effects of the irradiation by the synchrotron radiation emission, the thermal one, has been already discussed. In this section, we will see other consequences on the mirrors submitted to extreme environmental conditions, say under Ultra-High Vacuum (UHV) and synchrotron emission.

Since the beginning of the SRFEL experiments, the mirrors of the cavity, once irradiated, undergo a degradation of their reflectivity characteristics, say the losses increase. Some measurements performed on mirrors irradiated in situ or in an irradiation apparatus placed in the experimental chamber show that the degradation rate is strongly dependent on different parameters :

1) The vacuum level. The experimental chambers of the synchrotron beamlines are under UHV, but there is always a residual presence of hydrocarbons, resulting from the outgassing of the chamber walls induced by the radiation. In the Super-ACO experiment, the pressure of the chamber was lowered by a factor 5, enhancing the lifetime of a couple of mirror in the cavity by quite the same factor.

2) The deposition technique. Some tests reported in earlier works[6] and which most remarkable results are shown in fig. 8, indicate that a higher degradation rate occurs for mirrors manufactured by classical evaporation, while mirrors made with Ion beam assisted techniques, especially Ion Beam Sputtering (IBS) have lower degradation

rates, down to a factor 50. This is certainly correlated to the higher degree of amorphism and homogeneity of the films.

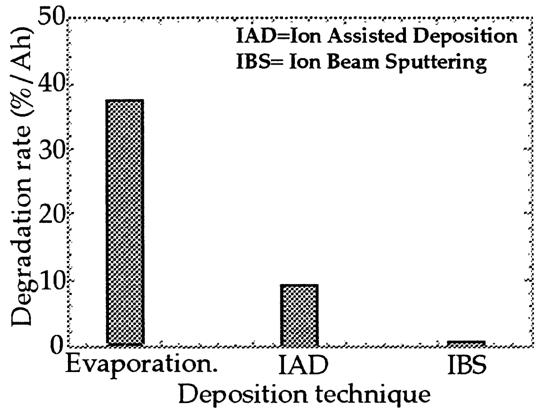


Fig 8 Degradation rate (losses/received dose) observed on different irradiated mirror sets

In the next sections, a review of some results is shown, concerning characterization at 300 nm and considerations on degradation

5. PRESENT PERFORMANCES AND VUV RANGE

Presently, laser oscillation at 350 nm is obtained by the use of a set of Ta2O5/SiO2 mirrors by Balzers, coated by IBS technique. Their total losses vary between 0.1 % for the best mirror with silica substrate and 1 % for the worst with sapphire one. Generally speaking, sapphire susbtrate exhibit higher roughnesses, because of the hardness to polish them. Consequently, scatter losses are higher than for the silica ones. This is not so crucial at this wavelength, but scatter become more important for the 200-350 nm wavelength range.

a)Roughness

An example of a correlation between roughness on substrates and total losses and some preliminary results on roughness and scattering losses on substrates are respectively shown in fig 9a and 9b. Former measurements are performed on a set of ZrO2/SiO2 mirrors centered at 300 nm, furnished by Cilas/Laserdot, which company we have a strict collaboration with. Latter measurements are done with substrates polished by different companies. It is clear the role of scattering term and also that a simple criterion lead to choose substrates having roughnesses lower than 2 Å.

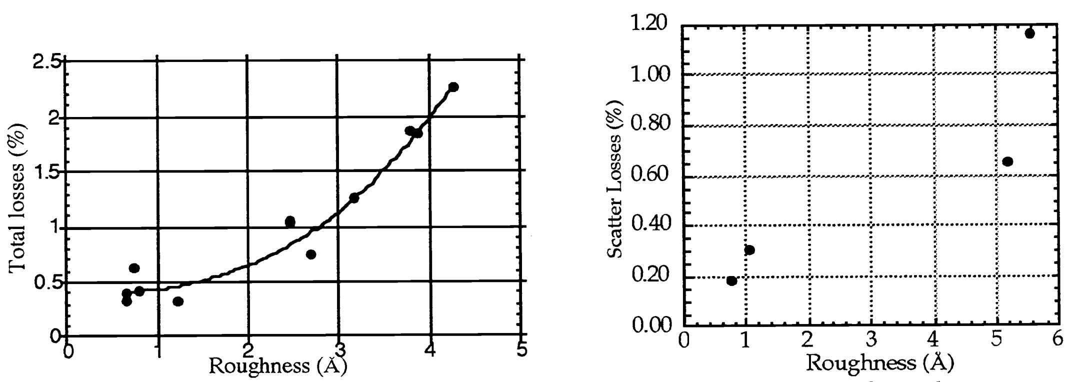


Fig. 9 Left: Correlation between total losse of the mirrors and measured roughness
Right : Correlation between measured scattered losses and roughness

b)Absorption

From fig. 9a, an extrapolation at zero roughness show the remanent absorption which is not negligible. In this range, low index material is supported by SiO2, which is transparent down to 185 nm, but unfortunately, from a general law[13], the higher the refractive index, the higher the extinction coefficient k. In the Visible-near UV spectral region there are not many transparent dielectric materials, for the high refractive index. Only oxydes of the IIIB, IVB and VB group of the periodical table of the elements are available, but below 300 nm some of them become very absorbant.

Generally, all the considerations on optical properties of materials are referred to the bulk materials. The same properties can vary a lot when one is dealing with thin films. In the last years however, studies performed on films deposited by new deposition techniques, in particular the ion beam assisted ones[14], show that the more amorphous and homogeneous is the film, the closer to the bulk state are the optical properties.

Extinction coefficients for films prepared by Magnetron Sputtering of ZrO_2 and HfO_2 are in the litterature[15], K_{ZrO_2}=33 10^{-4} and K_{HfO_2}=37 10^{-4}. Preliminary measurements effectued in LURE on the "mirage effect" bench showed, in the case of mirrors centered at 300 nm coated by IBS technique, the following results : K_{ZrO_2}=1.3 10^{-2} and K_{HfO_2}=1.4 10^{-2}.

c) Optical Density

Optical density measured at these wavelengths show that only ZrO_2 and HfO_2[16,17,18] appear to be good materials for the high index layers, but they seem to show some unfortunate features under extreme environmental conditions. One possibility is given by AL_2O_3 employed as high index material, but the weak difference with the SiO_2 index means that is necessary a higher number of periods to make a HR mirror, and as a consequence, the reflectivity bandwidth of the mirrors becomes narrower.An example of the optical density measured with the CARY spectrometer shows that the bandwidth of the mirrors $ZrO_2/SiO_2$is about 30 nm at 3 Db of losses and is extremely lower for AL_2O_3/SiO_2 (fig. 10).

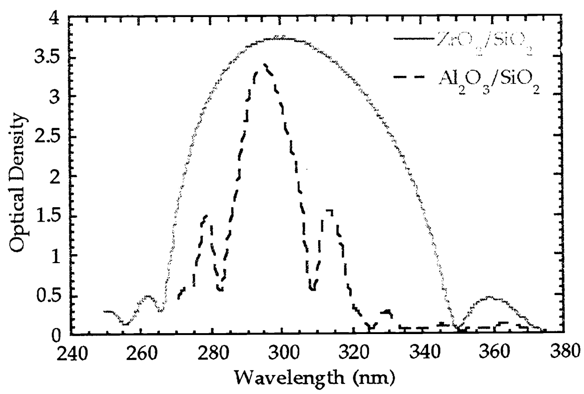


Fig 10 Optical Density spectrum of two mirrors centered around 300 nm.
Bandwidth at 3 Db is different because of the higher index gap for ZrO_2/SiO_2 than for Al_2O_3/SiO_2

6. RESULTS ON DEGRADATION MONITORING

"In Situ" measurements on cavity losses during irradiation show their increase versus time. More precisely, an investigation of the degradation rate versus the received dose of radiation shows a decrease of the rate towards an asymptotic behaviour which is not void[6]. One possible explanation can be the deposit of carbon on the mirror as result of the interaction of VUV radiation with residuals gases, leading to an adsorption on the surfaces. This is well confirmed by experience [ ] and observation on the mirrors pulled out of the cavity after irradiation.

Optical density measurements on HfO_2/SiO_2 mirrors coated by IBS technique show also a spectral shift of about 5 nm towards the red part of the spectrum. This can be explained only by a change in the optical thickness or in the refractive index of the layers and it means that the layer is also chemically modified, not only in the surface. We can also observe that the Optical Density increased and if we measure this increase on the secondary maximum of the spectrum, this correspond to an increase of the losses on all the volume. Otherwise, measurements performed by "mirage effect" on the same mirror, shown in fig 11, exhibit an increase by a factor 10 on the absorption. For mirrors coated on silica substrates an increase by a factor 100 has been observed.

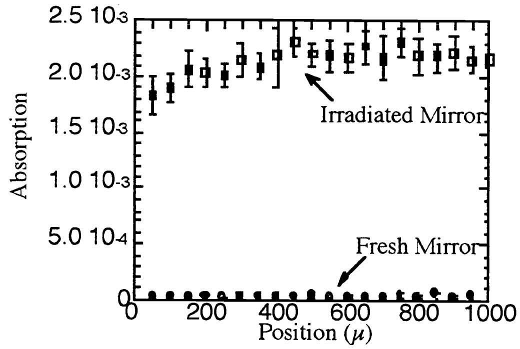


Fig. 11 Absorption meausrements on irradiated and fresh mirrors from the same set, centered at 350 nm

Moreover, a new phenomenon has been observed during a measurement performed as a function of time [: the "mirage" signal shows a characteristic decay of the absorption and if the observation point is displaced, this decay is perfectly reproduced. We suppose that these preliminary results show the presence of an optical bleaching induced by the Argon blue light, which recovers the absorption losses. This, together with the higher absorption rate observed on the mirror with silica substrate, suggest some speculations on the nature of this absorption increase. It is known[19] that even in amorphous systems like glasses and various oxydes, the non stoichiometry of the oxygen leads to the formation of point defects like vacancies. The irradiation by X and gamma rays can induce the activation of absorption centers in these vacancies. Studies has been made for Silica, Alumina and metal transition oxydes, but there is a lack of studies for amorphous materials like Zirconia and Hafnia.

Non Optical Characterization Techniques

Novel experiments performed on test mirrors with the Secondary Ion Mass Spectrometry (SIMS)[20] give interesting preliminary results on the layered structure of the mirror, especially at the interfaces. They seems to confirm a non stoichiometry of oxygen in the SiO_2 layers and also a non negligible amount of carbon not only at the surface of the mirror, but even in the inner layers. Additional measurements are required to validate these observations.

Losses Recovery

The enhancement of the mirrors losses is a reversible phenomenon. Previous results on Super ACO show clearly that losses can be recovered by submitting the mirrors to a stage of RF discharge-activated Oxygen Plasma[21] in which atomic and molecular oxygen at sub-atmospheric pressures (10^{-2}-10^{-1} torr) is in contact with the mirror surface.

This process recovers up to 90 % of the acquired losses acting on the carbon present on the mirror surface and forming CO_2.

This recovery technique is generally coupled, in the Super ACO experiment, to a stage of annealing at 300 °C during twelve hours. Results show sometimes the recovery up to 100 % of acquired losses for the two techniques together.

These observations and the measurement of total losses show only partially what are the phenomena occurring during the irradiation. It is then necessary to use other characterization techniques by optical and non optical methods in order to explain what are the actual causes of degradation and on which term of losses they act.

7. CONCLUSIONS

In this work there was a principal aim to make a general review on the positive and negative features encountered in the FEL operation in the UV from the point of view of the cavity mirrors. Initial losses must be maintained to very low level (< 0.5 %), thus precise characterizations have to be made at all levels of manufacture. Moreover, in order to avoid a degradation during the irradiation, characteristics of materials, homogeneity and purity of layers must be tested previously with a big effort of collaboration between researchers (in optics and Free Electron Laser) and manufacturers. Last two years showed a great improvements on the performances of the Super ACO FEL, but it is necessary to concentrate this effort towards the spectral range between 200 and 350 nm, which presently is not really supported by the manufacturers market.

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