Polarization and reflectivity changes on mirror based viewing systems during long pulse operation

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Summary

- The Model
  - Mirror Reflection with Metallic Coating
- Model Results – C and Be coating on Au mirror
- The ITER MSE case
- Discussion & Conclusion

Long pulse operation

ITER typical plasma discharge:
400 s, $T_i \approx 23$ keV, $T_e \approx 30$ keV and $n_e \approx 1\times10^{20}$ m^{-3}
Total erosion rates 10^{22} atom/s

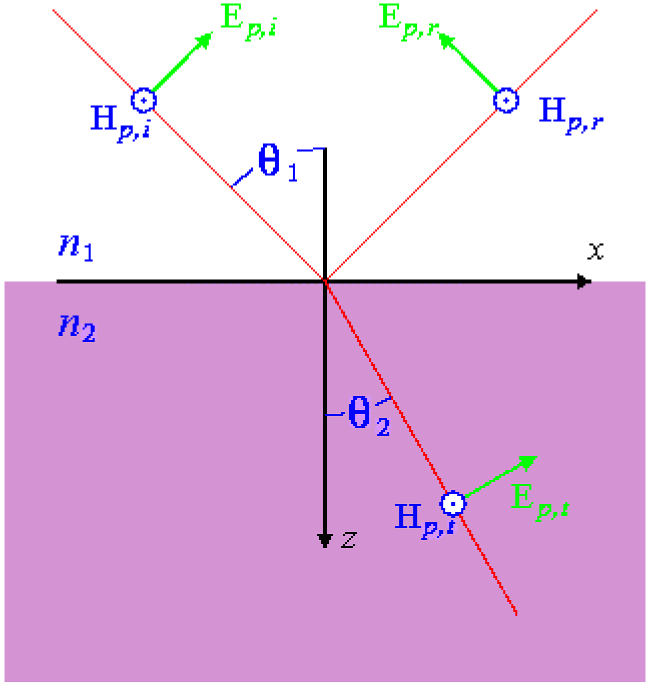
Erosion and deposition will play a balanced role depending on location
First wall mirrors recessed in cavities are expected to suffer manly from deposition of Be and C

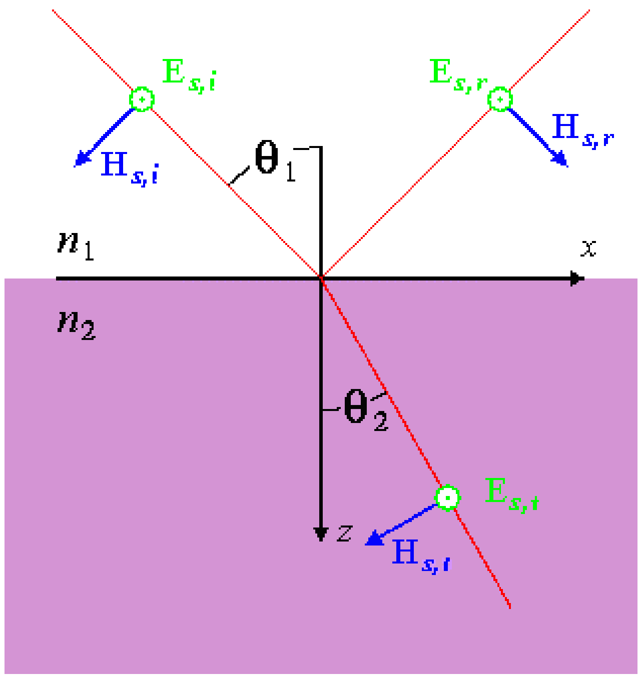
FW deposition rate of C in ITER at equatorial level ~ 0.09 Ang./s

(see André Kukushkin presentation in this conference)

Reflection and light transmission

- Any polarized light state can be decomposed in two linear polarized components, s and p, having a fase difference ϕ.
- When light passes from media 1 to media 2, Maxwel equation's solutions for the specific boundaries give the *Fresnel Formulae*





Pictures from D. J. De Smet, 1995

Fresnel Formulae (transmission *t* and reflection *r* coeff.)

S component:

$$r_s = \frac{n_1 \cos q_1 - n_2 \cos q_2}{n_1 \cos q_1 + n_2 \cos q_2}$$

$$t_s = \frac{2 n_1 \cos q_1}{n_1 \cos q_1 + n_2 \cos q_2}$$

For metals *n* and q are imaginary

$$\bar{n}_2 = n_2 (1 - i k_2)$$

k_2 , absorption index

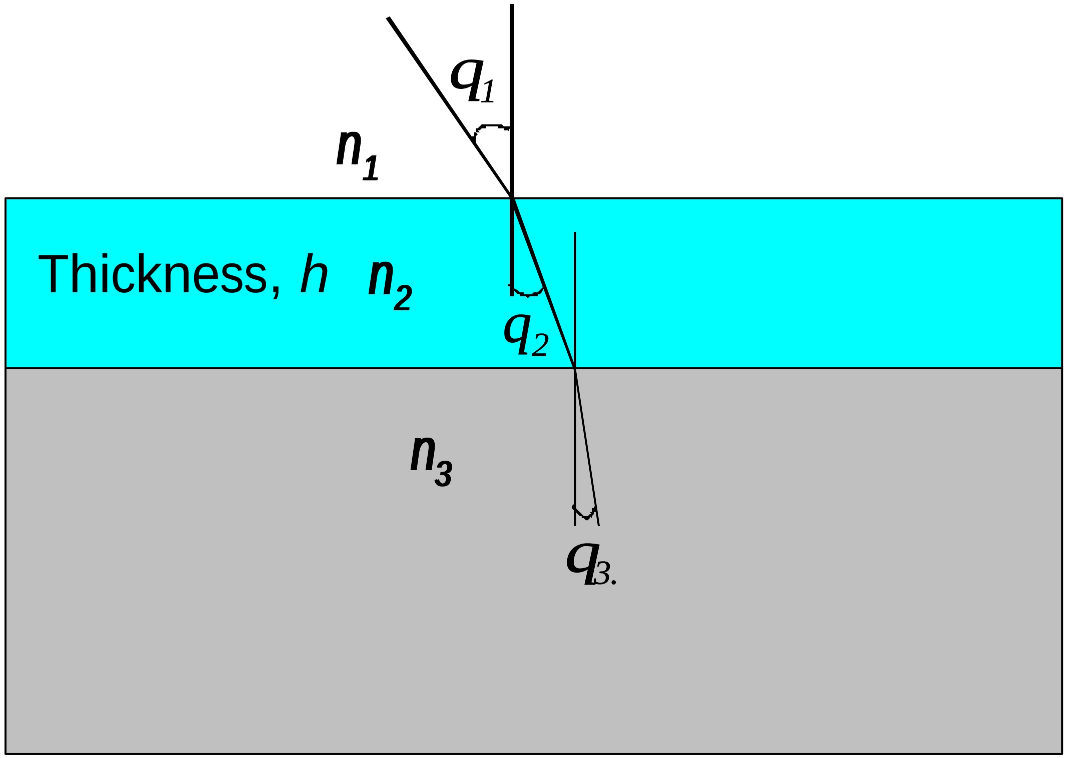
p component:

$$r_p = \frac{\dfrac{\cos q_1}{n_1} - \dfrac{\cos q_2}{n_2}}{\dfrac{\cos q_1}{n_1} + \dfrac{\cos q_2}{n_2}}$$

$$t_p = \frac{\dfrac{2 \cos q_1}{n_1}}{\dfrac{\cos q_1}{n_1} + \dfrac{\cos q_2}{n_2}}$$

Born & Wolf, “Principles of Optics”

Mirror reflection with metallic coating



$$\overline{n}_2 = n_2(1 - ik_2)$$

$$\overline{n}_3 = n_3(1 - ik_3)$$

Mirror Reflection with metallic coating

Formaly, one can use similar approach as for the case of stratified media: dielectric/metallic-film/dielectric[+] replacing real index n_3 by imaginary index $\bar{n}_3$

Defining:

$$\bar{n}_2 \cos\bar{\theta}_2 = u_2 + iv_2$$

$$\bar{n}_3 \cos\bar{\theta}_3 = u_3 + iv_3$$

Using Snell's law:

$$n_1 \sin\theta_1 = \bar{n}_2 \sin\bar{\theta}_2 = \bar{n}_3 \sin\bar{\theta}_3$$

and

Using:

$$\cos^2\theta + \sin^2\theta = 1$$

[+] Born & Wolf, "Principles of Optics"

Mirror Reflection with metallic coating

One obtains:

$$2u_2^2 = n_2^2(1-k_2^2) - n_1^2 \sin^2 \mathbf{q}_1 + \sqrt{\left[n_2^2(1-k_2^2) - n_1^2 \sin^2 \mathbf{q}_1\right]^2 + 4n_2^4 k_2^2}$$

$$2v_2^2 = -n_2^2(1-k_2^2) + n_1^2 \sin^2 \mathbf{q}_1 + \sqrt{\left[n_2^2(1-k_2^2) - n_1^2 \sin^2 \mathbf{q}_1\right]^2 + 4n_2^4 k_2^2}$$

and

$$2u_3^2 = n_3^2(1-k_3^2) - n_1^2 \sin^2 \mathbf{q}_1 + \sqrt{\left[n_3^2(1-k_3^2) - n_1^2 \sin^2 \mathbf{q}_1\right]^2 + 4n_3^4 k_3^2}$$

$$2v_3^2 = -n_3^2(1-k_3^2) + n_1^2 \sin^2 \mathbf{q}_1 + \sqrt{\left[n_3^2(1-k_3^2) - n_1^2 \sin^2 \mathbf{q}_1\right]^2 + 4n_3^4 k_3^2}$$

Mirror Reflection with metallic coating

From Fresnel formulae we obtain the reflection coefficients between the interfaces:

$$r_s^{1\to 2} = \frac{n_1\cos(\theta_1) - (u_2 + iv_2)}{n_1\cos(\theta_1) + (u_2 + iv_2)} \qquad r_p^{1\to 2} = \frac{\dfrac{\cos(\theta_1)}{n_1} - \dfrac{(u_2 + iv_2)}{\bar{n}_2^2}}{\dfrac{\cos(\theta_1)}{n_1} + \dfrac{(u_2 + iv_2)}{\bar{n}_2^2}}$$

$$r_s^{2\to 3} = \frac{u_2 + iv_2 - (u_3 + iv_3)}{u_2 + iv_2 + u_3 + iv_3} \quad ; \quad r_p^{2\to 3} = \frac{\dfrac{u_2 + iv_2}{\bar{n}_2^2} - \dfrac{u_3 + iv_3}{\bar{n}_3^2}}{\dfrac{u_2 + iv_2}{\bar{n}_2^2} + \dfrac{u_3 + iv_3}{\bar{n}_3^2}}$$

Mirror Reflection with metallic coating

The final reflection coefficients for *s* or *p* component are given by Airy formulae :

$$r_{s,p} = \frac{r_{12} + r_{23} e^{2ib}}{1 + r_{12} r_{23} e^{2ib}}$$

With: $b = 2p \frac{h}{l} \bar{n}_2 \cos \bar{q}_2$

Mirror Reflectivity (s,p): $R_i = r_i r_i^*$

$$phase\ difference = Arg(r_p) - Arg(r_s)$$

Born & Wolf, “Principles of Optics”

Stokes vectors

Stokes vectores describe polarization state of light:

$$S = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}$$

$$I = \langle E_x^2 \rangle + \langle E_y^2 \rangle \qquad Q = \langle E_x^2 \rangle - \langle E_y^2 \rangle$$

$$U = \langle 2E_x E_y \cos(y_x - y_y) \rangle \qquad V = \langle 2E_x E_y \sin(y_x - y_y) \rangle$$

Linear polarization fraction: $p = \dfrac{\sqrt{Q^2 + U^2}}{I}$

Angle of elipse major axis to *x* axis: $c = \dfrac{\arctan(U/Q)}{2}$

J. Biretta and M. McMaster, 1997 "WFPC2 Polarization Calibration"
STScI Instrument Science Report WFPC2 97-11 (Baltimore: Space Telescope Science Institute)

Muller matrix of a mirror

Muller matrix describes optical properties of a given system and operates on Stokes vector. For a mirror one as:

$$\begin{bmatrix} I' \\ Q' \\ U' \\ V' \end{bmatrix} = \begin{bmatrix} A & B & 0 & 0 \\ B & A & 0 & 0 \\ 0 & 0 & C & -D \\ 0 & 0 & D & C \end{bmatrix} \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix}$$

With:

$$A = \frac{R_s + R_p}{2}$$

$$B = \frac{R_s - R_p}{2}$$

$$C = \sqrt{R_s R_p} \cos(f_p - f_s)$$

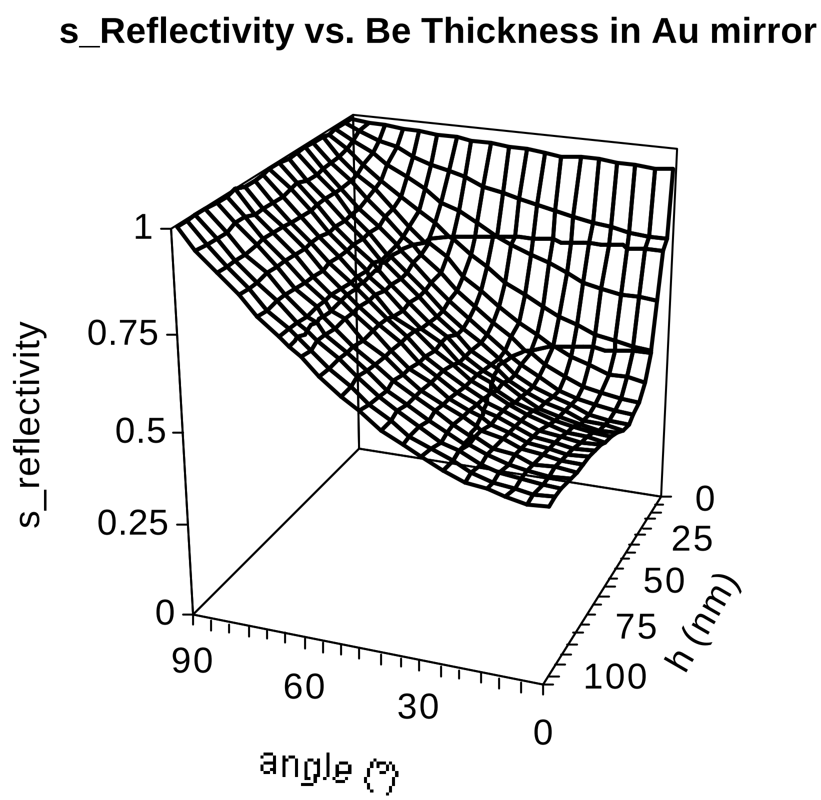
$$D = \sqrt{R_s R_p} \sin(f_p - f_s)$$

R is the mirror reflectivity

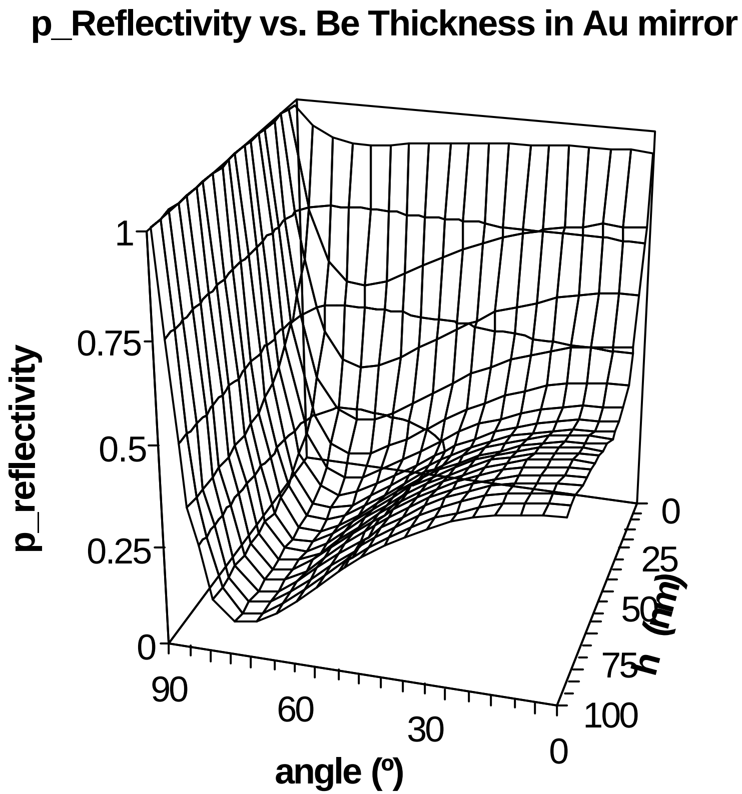
J. Biretta and M. McMaster, 1997 "WFPC2 Polarization Calibration“
STScI Instrument Science Report WFPC2 97-11 (Baltimore: Space Telescope Science Institute)

And Seagraves and Elmore 1994

Be deposition on Au surface



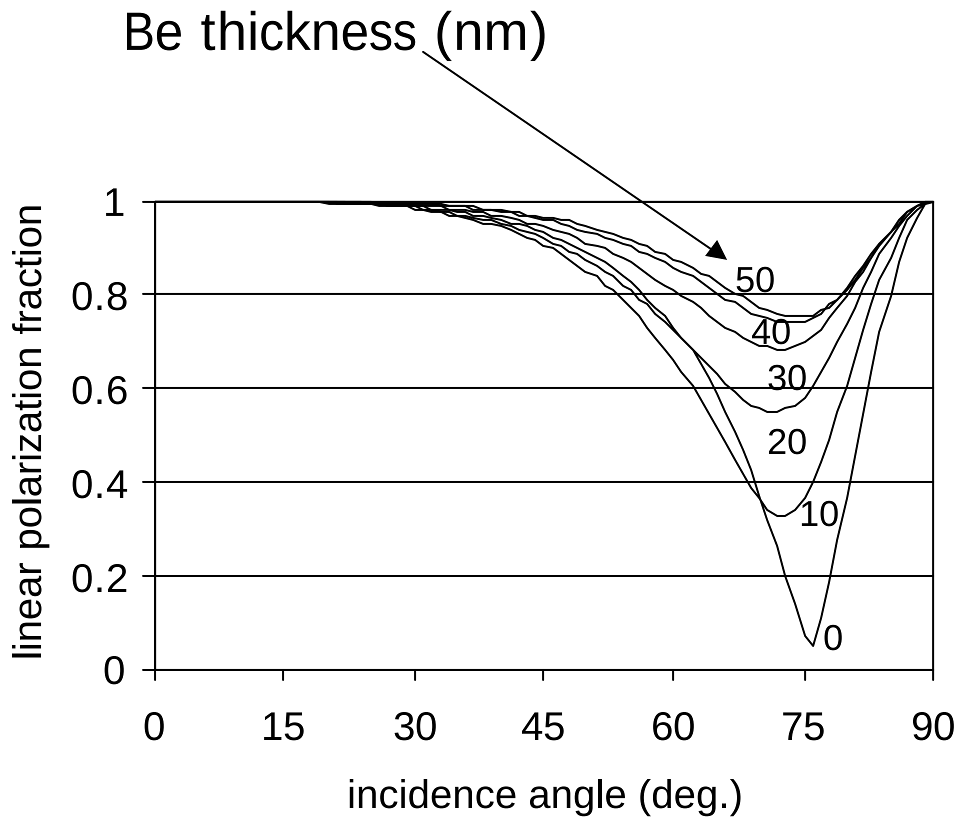
Be deposition on Au surface



Be deposition on Au surface

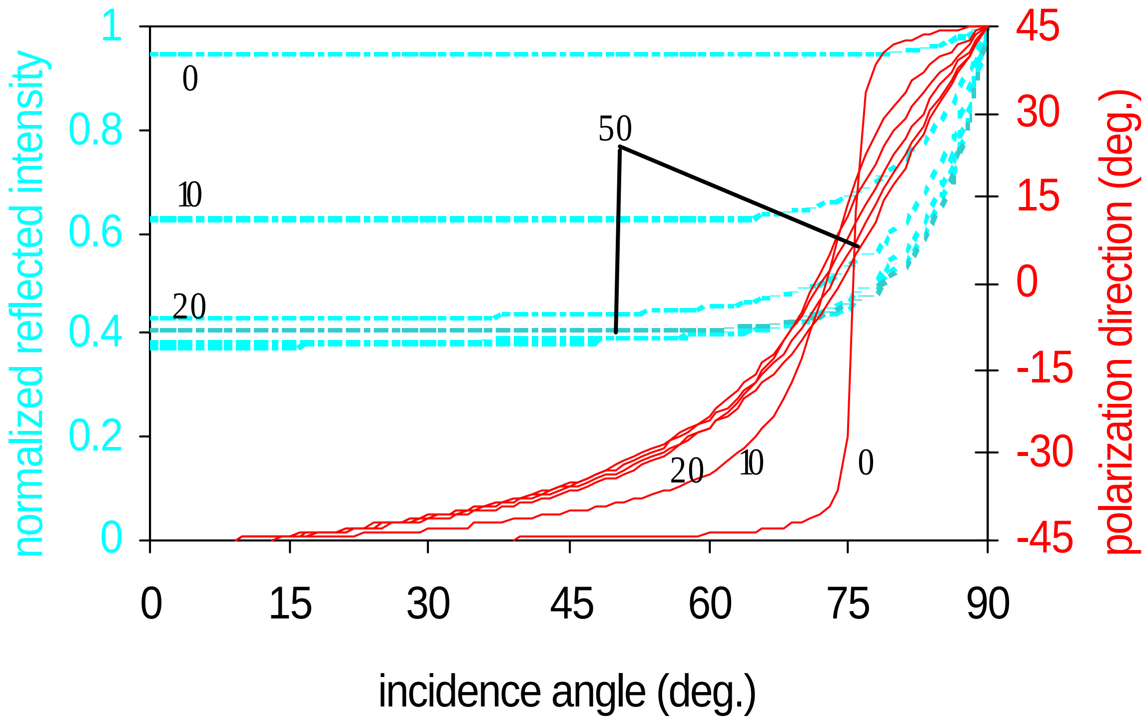
Light polarization state is affected by Be deposition

Input light:
LPF=1



Be deposition on Au surface

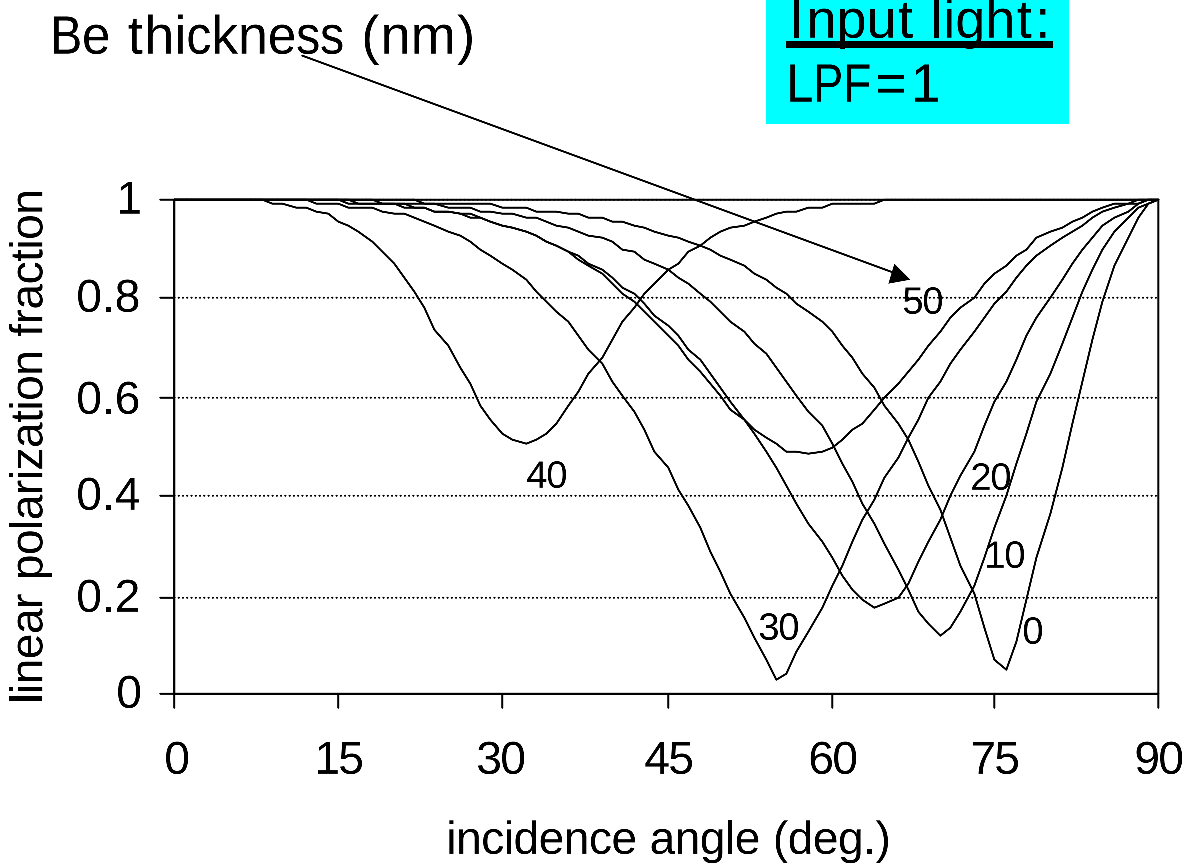
Input light:
Azimuth=45 deg.



C deposition on Au mirror

Input light:
LPF=1

Large changes on the LPF implying that ellipticity of light is strongly affected



C deposition on Au mirror

Input light:
Azimuth=45 deg.

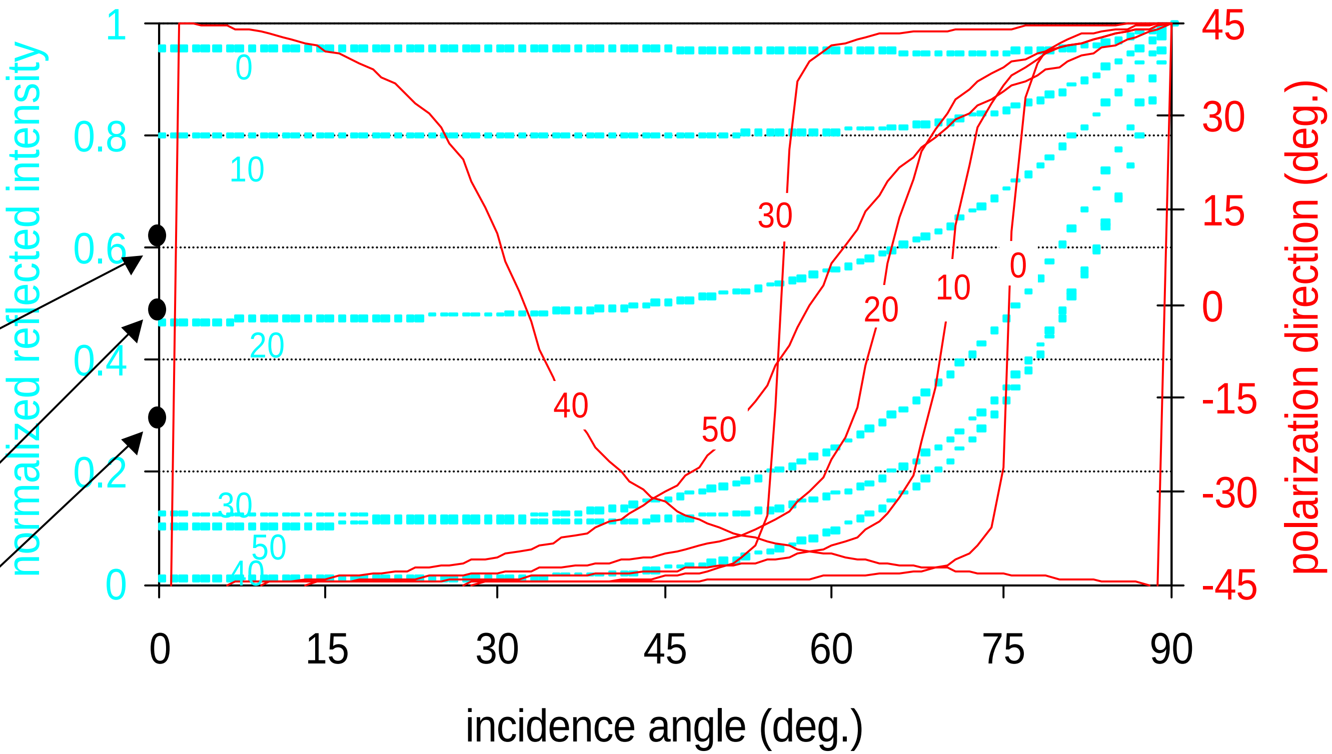
Intensity of reflected light for 40 nm C layer is ~zero for θ<45 deg..

Also, polarization direction evolution is reversed

SS

SS (C-11nm)

SS (C-21nm)



V. Voytsenya Rev. Sc. Inst. V72 (2001) 475

The ITER MSE case

MSE efect will generate polarized light

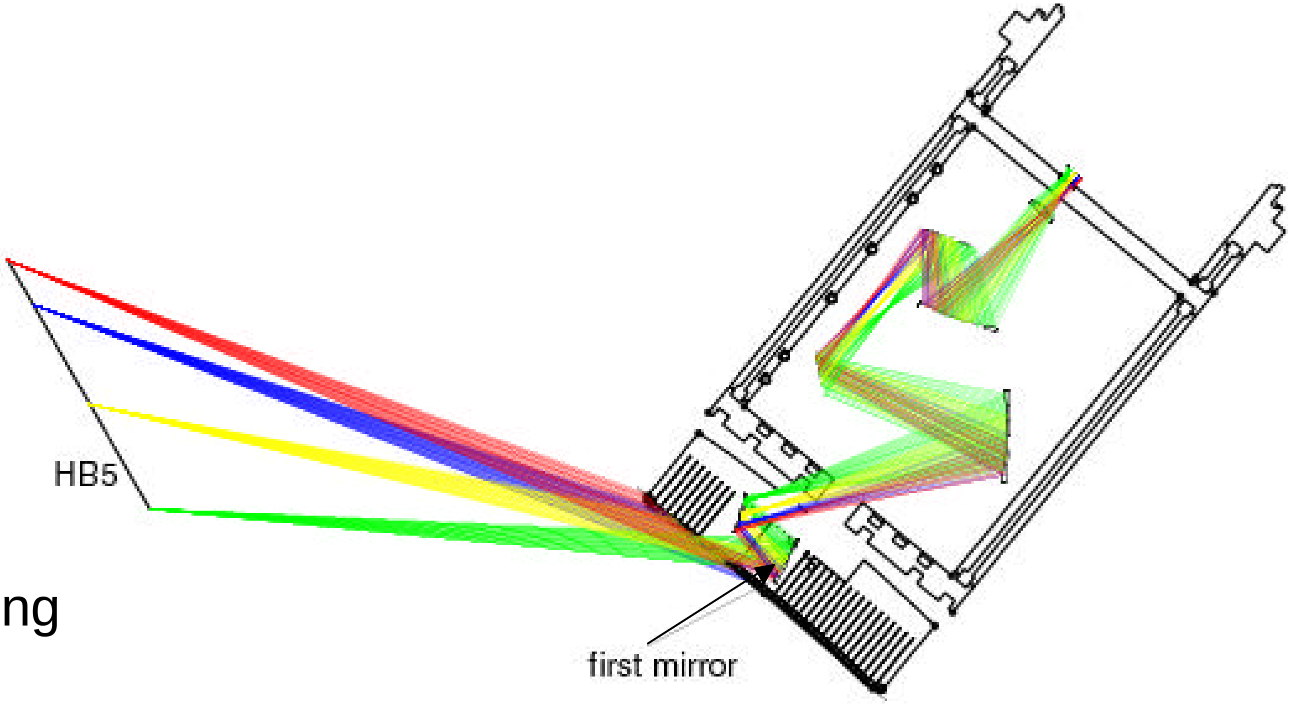
Light must be collected by a mirror arrangement

The reflected light properties change as a function of deposited material on mirror´s surface

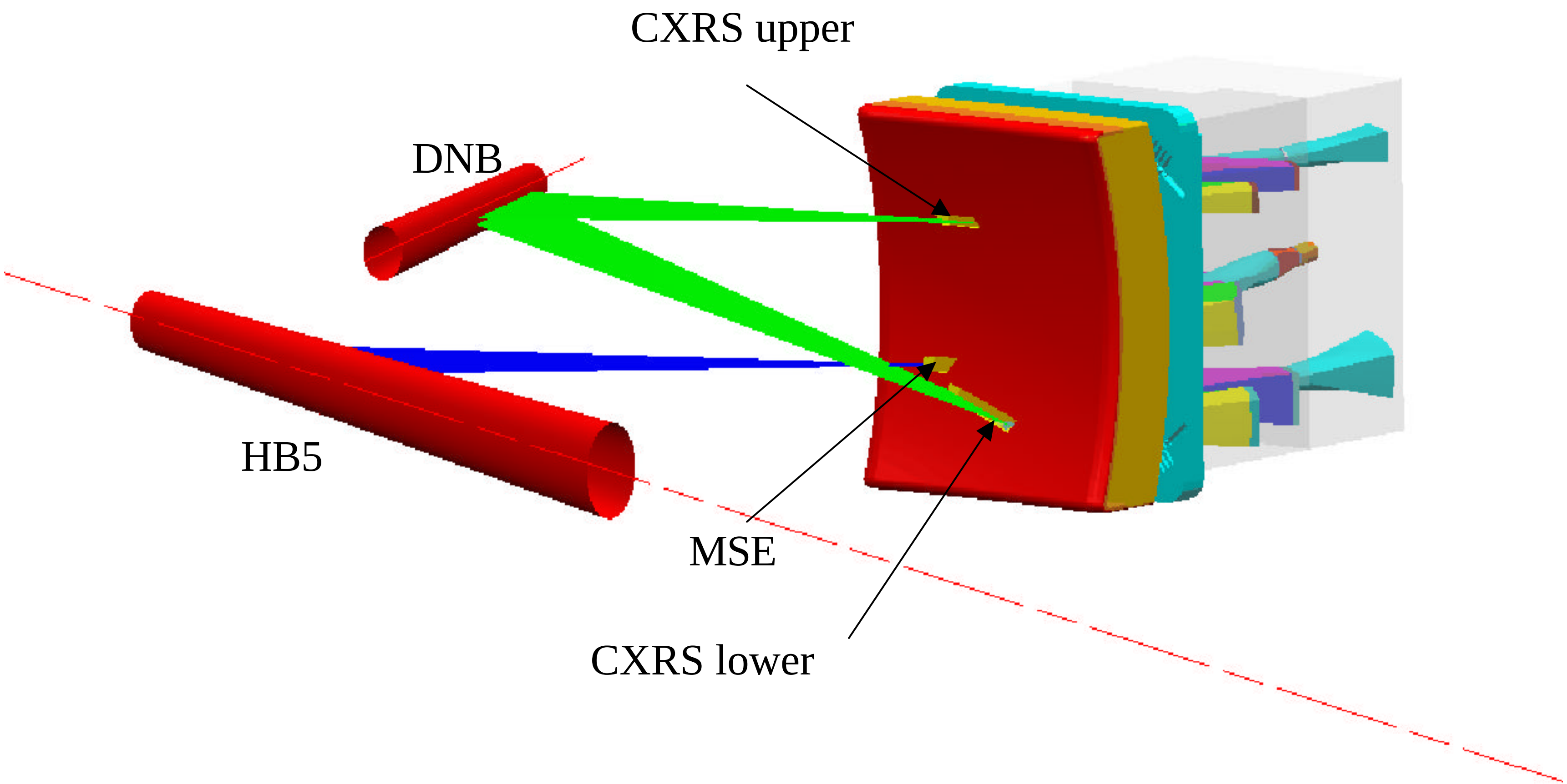
The ITER MSE

Requirements:

- F/# ~ 3 at image
- Demag. ~ 20x
- Low incidence angles
- Good labyrinth shielding



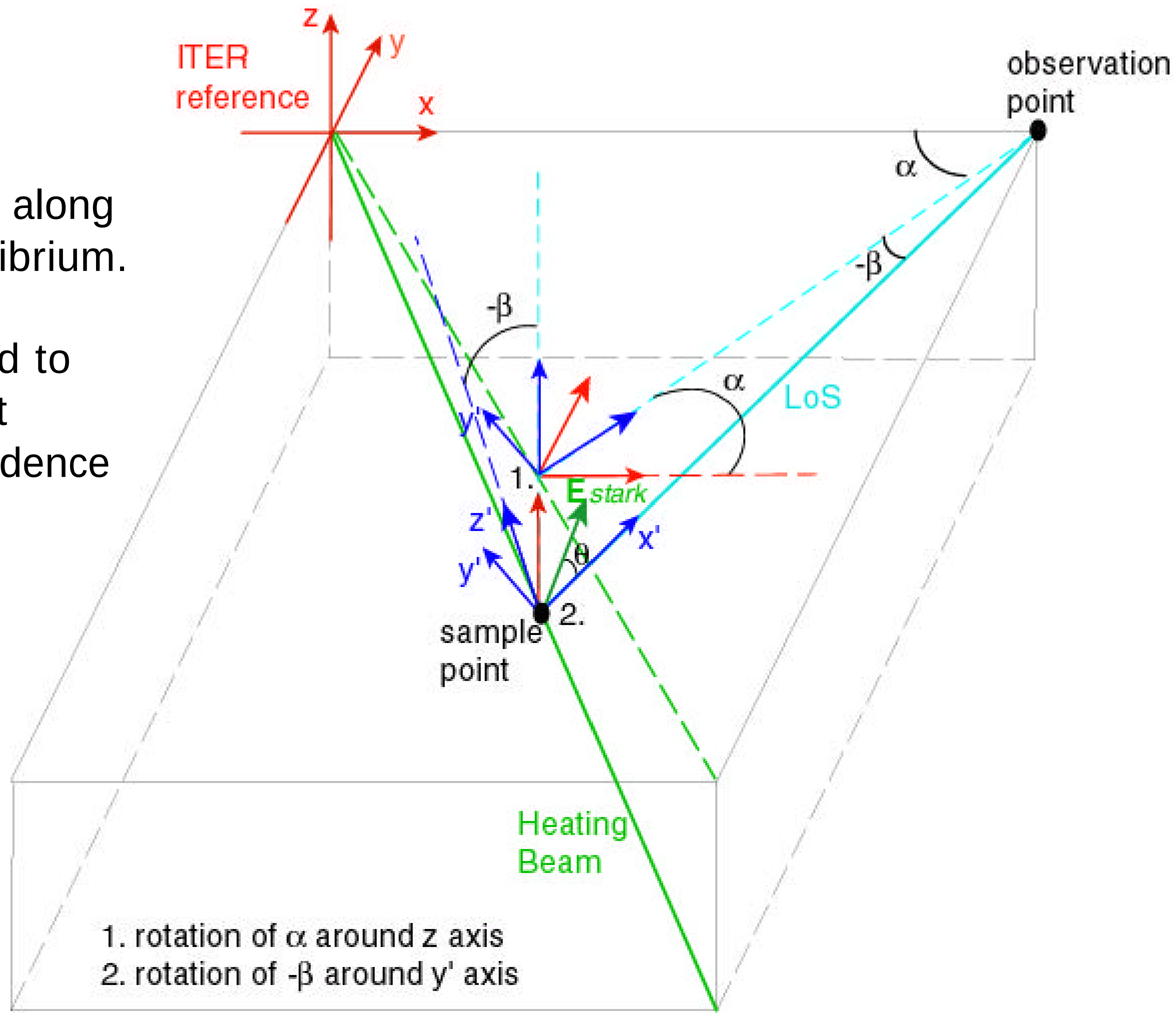
The ITER MSE – arrangement in the port plug



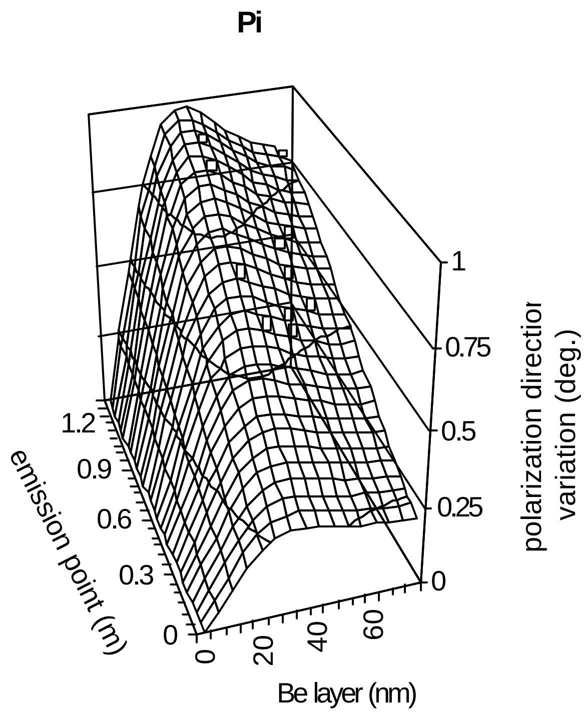
The ITER MSE

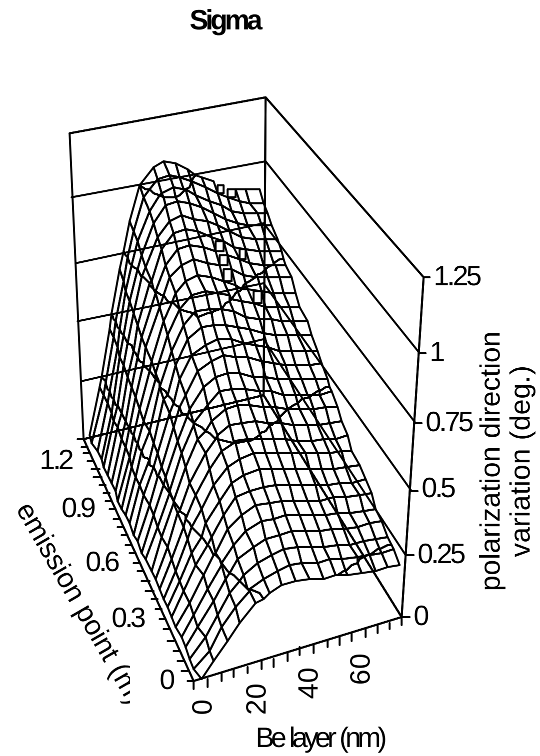
The Stark vector was computed along the beam path for a given equilibrium.

A set of Euler rotations was used to represent the Pi and Sigma light components on the mirror‘s incidence plane decomposed in s and p conponents



Change on polarization direction





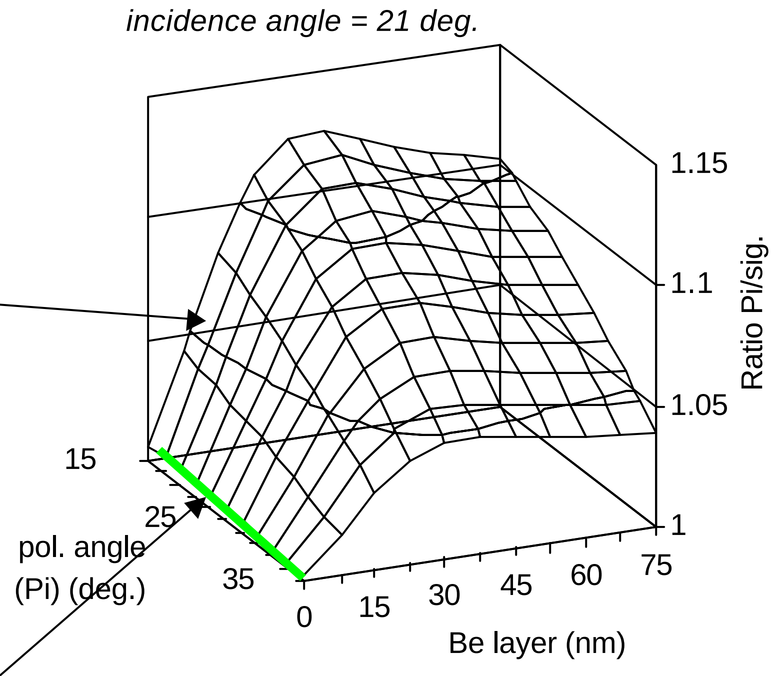
Uncertainities in polarization orientation are reflected in achievable spatial resolution: 1 deg. → a/13

Ratio pi / sigma

Intensity ratio (R) changes with Be layer and input angle of polarization

(pi and sigma intensities were normalized to 1)

In the worst case, error can be ~13%



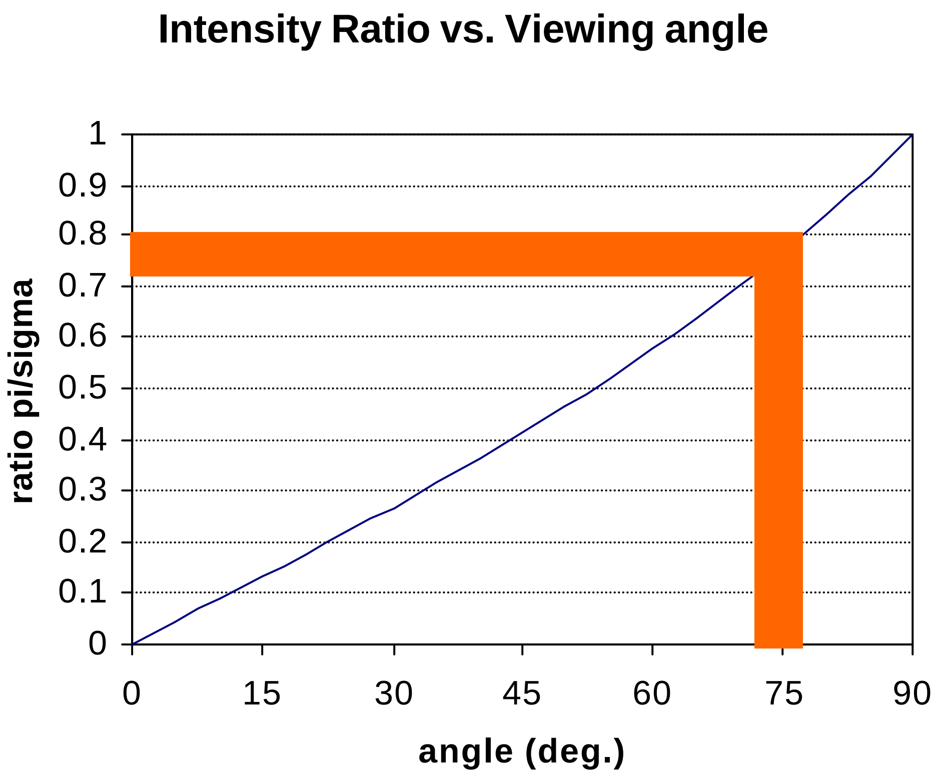
If no coating is present the ratio is almost constant with incident polarization orientation

Ratio pi / sigma

$$R_{pi/sigma} = \frac{|\sin(q)|}{1+\cos(q)}$$

For the ITER viewing angle of 105 deg. and pi azimuth in plane of incidence of 15 deg. the ratio pi/sigma is 0.767.

The orange bars includes a 10% error in the ratio, representing an unaccuracy of about 5 deg. on the determination of Pi orientation



Conclusions

A model to evaluate the effects on light reflected of a metallic mirror containing a metal deposit on its surface was developed.

The effects of Be and C deposition onto Au mirror have been computed and the results show that these deposits will affect the light polarization state and mirror reflectivity.

It is found that the Au mirror will behave mostly like a Be mirror after a 50 nm coating has been deposited.

Carbon deposit induces stronger optical changes on the Au mirror than Be deposit.

Conclusions

In the ITER MSE case:

Induced changes on polarization angle azimuth can increase up to 1 deg due to Be deposit.

The intensity ratio can be affected up to 13% implying > 5 deg. uncertainity on Pi azimuth if not calibrated.

To reduce these uncertainities the first mirror optical state must be controled/monitored. For the case of ITER MSE the use of first mirror as Be may help to reduce the expected optical transition induced by Be deposit but C deposit may be of a more serious concern.

The induced changes on Pi polarization azimuth have a direct impact on the achievable spatial resolution. For this particular equilibrium and viewing geometry (0.5<r/a<1) the angular spread fo Pi light along the beam is ~ 6.5 deg.Therefore, to a 1 deg. azimuth uncertainity corresponds an average spatial resolution of a/13 (the requirements are for a/20).