

Solar-C_EUVST

Extreme UltraViolet High-Throughput Spectroscopic Telescope



SW and LW gratings ruling for SOLAR C - ITT

SOLC-IAS-EGA-ITT-007

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1 Scope

Solar-C est une mission de la JAXA (agence spatiale japonaise) en collaboration avec l'Europe (ESA et les agences Allemande, Italienne et Suisse) et les USA (NASA).

Solar-C EUVST (EUV High-throughput Spectroscopic Telescope) constitue la prochaine génération de satellites d'observation du Soleil, et est conçu pour dévoiler les mécanismes liés au chauffage du plasma et les effets du Soleil sur la Terre.

Solar-C EUVST résoudra les mystères de l'atmosphère de notre étoile en analysant le spectre UV du rayonnement solaire. En collaboration étroite avec les partenaires américains et européens, IASA / JAXA (Institute of Space and Astronautical Science) et NAOJ (National Astronomical Observatories of Japan) développent EUVST en vue d'atteindre une sensibilité et une résolution meilleure que celles des spectromètres EUV précédents. Le lancement de la mission est prévu en novembre 2028

Dans ce contexte, l'IAS (Institut d'Astrophysique Spatiale) fournit le EUVST Grating Assembly (EGA, ensemble réseau de EUVST). L'EGA est composé de deux réseaux de diffraction collés et intégrés dans une monture mécanique permettant un réglage de mise au point.

Le premier réseau est utilisé pour les courtes longueurs d'ondes (SW, short wavelengths), le second pour les grandes longueurs d'onde (LW, long wavelengths).

Les gammes de longueur d'onde sont les suivantes :

SW : [17,1 nm : 21,23 nm]

LW : [71,91 nm : 122,09 nm]

L'objet de cet appel d'offres est la réalisation de la gravure des traits et découpe des réseaux SW et LW sur des substrats en silice fournis par l'IAS ainsi que leur découpe. Cet appel d'offre comporte 2 lots :

Lot 1 : gravure des traits et découpe des réseaux gravés SW

Lot 2 : gravure des traits et découpe des réseaux gravés LW

Les deux types de substrats sont des ellipsoïdes hors axe de définitions différentes dont les spécifications sont données dans le document [RD1] et rappelées ici.

Leur fabrication a fait l'objet d'un précédent marché attribué à l'entreprise Bertin.

L'IAS fournira les substrats nécessaires à la réalisation des gravures des réseaux des deux lots :

Pour le lot 1 :

- Au total 8 substrats SW seront fournis par l'IAS pour permettre la livraison finale de 3 réseaux SW répondant aux spécifications.
- Les deux premiers substrats seront livrés au plus tard le 1er Avril 2025
- Les autres substrats seront livrés par groupes de 2 échelonnés jusqu'à juin 2025

Pour le lot 2 :

- au total 8 substrats LW seront fournis par l'IAS pour permettre la livraison finale de 3 réseaux LW répondant aux spécifications.
- Les deux premiers substrats seront livrés au plus tard le 1^{er} mai 2025
- Les autres substrats seront livrés par groupes de 2 échelonnés jusqu'à juin 2025

Les plans de fabrication des substrats SW et LW sont également donnés pour information en annexe 1 et 2.

Les spécifications techniques, assurance qualité et management concernant la gravure des réseaux SW et LW sont listées dans ce document.

Les substrats sont de la responsabilité de l'IAS jusqu'à la réception et inspection d'entrée chez le titulaire.

Les réseaux sont sous la responsabilité du titulaire jusqu'à réception et inspection d'entrée à l'IAS

Solar-C is a JAXA mission with collaboration from Europe (ESA and the space agencies of Germany, UK, France, Italy, and Switzerland) and USA (NASA).

Solar-C **EUVST** (EUV High-throughput Spectroscopic Telescope) is the next-generation solar-observing satellite which will unravel the formation mechanisms of the hot plasma and Sun's effects on the Earth

Solar-C EUVST solves the mysteries of solar atmosphere by analyzing the spectrum of the Sun's extreme UV radiation. In close collaboration with the US and European partners, ISAS/JAXA and NAOJ are now developing EUVST to achieve higher sensitivity and resolution than any previous EUV spectrometer. The launch of the mission is at this time scheduled for November 2028.

In this context, IAS (Institut d'Astrophysique Spatiale) is providing the EUVST Grating Assembly (**EGA**). The EGA consists of two gratings bonded together and integrated in a mechanical mount with focus adjustment capabilities.

One grating is used to disperse light for a short wavelength range, this grating is there after referred to as SW grating.

The second grating is used to disperse light for a longer wavelength range, this grating is there after referred to as LW grating.

The wavelength ranges for both gratings are the following:

SW: [17,1 nm - 21,23 nm]

LW: [71,91 nm - 122,09 nm]

The scope of this public bidding is the ruling of the SW and LW gratings. The fused silica SW and LW substrates will be provided by IAS. This public bidding is split in 2 lots:

Lot 1: ruling and cutting of the SW gratings

Lot 2: ruling and cutting of the LW gratings

Their production was the subject of a previous public bidding and was awarded to Bertin.

IAS will supply enough substrates to yield the quantity of gratings requested:

Lot 1 :

- A total of 8 SW substrates will be provided by IAS to yield 3 gratings compliant to the specifications
- The first 2 substrates will be delivered to the vendor on April 1st 2025 at the latest
- The remaining 6 substrates will be delivered in sequence by group of 2 until end of June 2025

Lot 2 :

- A total of 8 LW substrates will be provided by IAS to yield 3 LW gratings compliant to the specifications
- The first 2 substrates will be delivered to the vendor on May 1st 2025 at the latest
- The remaining 6 substrates will be delivered in sequence by group of 2 until end of June 2025

The manufacturing drawings of the SW and LW substrates are given in annex 1 and 2 of public bidding

The technical, PA-QA and management requirements are listed in this document.

The substrates are under IAS responsibility until they are received and inspected by the vendor.

The gratings are under the vendor responsibility until they are received and inspected at IAS

2 Applicable Documents

2.1 Compliance documents

Compliance matrix

2.2 Applicable documents

2.3 Reference documents

Plan de fabrication Bertin pour « miroir substrats SW » en annexe 1

Plan de fabrication Bertin pour « miroir substrats LW » en annexe 2

Plan des réseaux forme finale « SW-grating » en annexe 3

Plan des réseaux forme finale « LW-grating » en annexe 4

3 Coordinates

coordinate	definition	Note
Origin O_g	At a point $z=-300$ mm in the local coordinate of the slit.	
Local z-axis	Line O_gP , $+z$ as the direction from O_g to P	$+z$ is toward the slit
Local xy-plane	Through O_g and normal to local z-axis	
Local y-axis	Line OP projected to local xy-plane, $+y$ as the direction from P to O	Local y-axis is the slit (spatial) direction projected to grating
Local x-axis	The remaining axis in the right-handed Cartesian coordinate system	Local x-axis is the dispersion (wavelength) direction, the direction of the gap between LW/SW gratings.

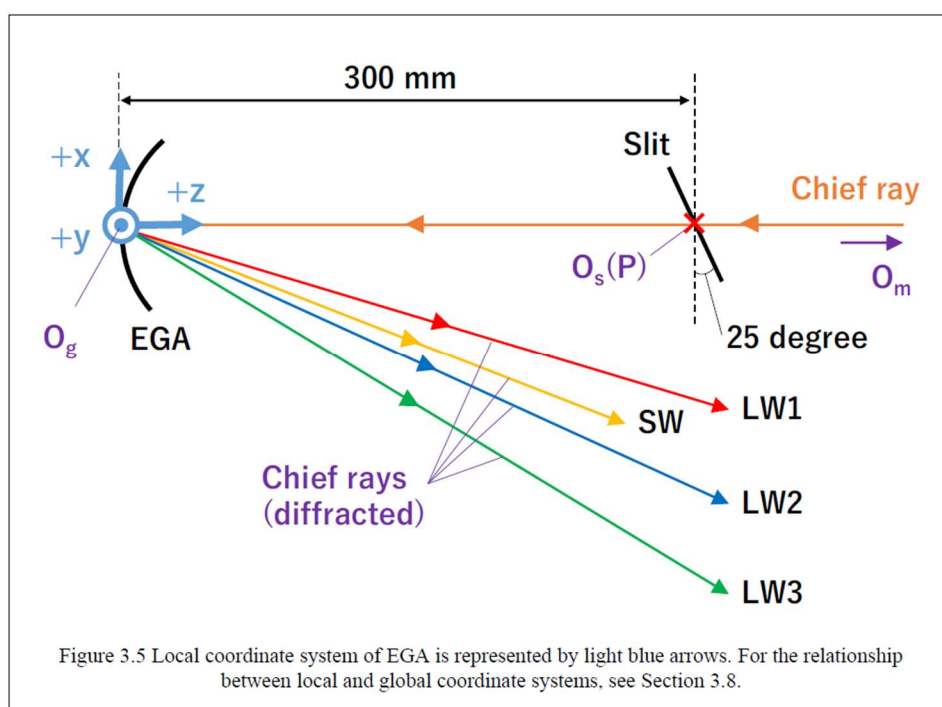


Figure 1 Definition of the local EGA coordinate system

4 Gratings technical requirements

La première colonne des tableaux de spécifications des réseaux donne le type de méthode de vérification souhaité de la part du titulaire :

D par design

I par inspection

S par simulation

T par test

The first column of the grating specifications shows the different methods of verification expected from the vendor:

D by design

I by inspection

S by simulation

T by test

4.1 LOT 1: SW gratings

4.1.1 SW substrate definition (for information only)

[Le plan de fabrication des substrats SW est donné en annexe 1](#)

The manufacturing plans of the SW substrates is given in Annexe 1

4.1.1.1 SW substrate coordinates definition

Figure 2 shows the relationship between the EGA local coordinate system and the coordinates that define the optical surfaces of SW (ξ_x , ξ_y , ξ_z), called the SW coordinate system.

The conversion between the SW coordinate and EGA local coordinate is given as follows:

$$\xi_x = 0.996060 X - 0.004875 Y + 0.088543 Z - 31.855804$$

$$\xi_y = 0.000000 X + 0.998488 Y + 0.054977 Z - 15.180780$$

$$\xi_z = -0.088678 X - 0.054760 Y + 0.994554 Z + 1.215498$$

The inverse conversion between the EGA coordinate and SW coordinate is given as follows:

$$X = 0.996060 \xi_x + 0.000000 \xi_y - 0.088678 \xi_z + 31.838092$$

$$Y = -0.004875 \xi_x + 0.998488 \xi_y - 0.054760 \xi_z + 15.069078$$

$$Z = 0.088543 \xi_x + 0.054977 \xi_y + 0.994554 \xi_z + 2.446336$$

We also define the coordinate system defined by the three planes corresponding to the three reference sides of the substrate (see annexe 1 and annexe 3). This system is called the substrate coordinate system. It has its axes parallel to those of the EGA system, but its origin is shifted to lie at the intersection of sides D, E & F (annexe 1 and annexe 3).

SW Grating

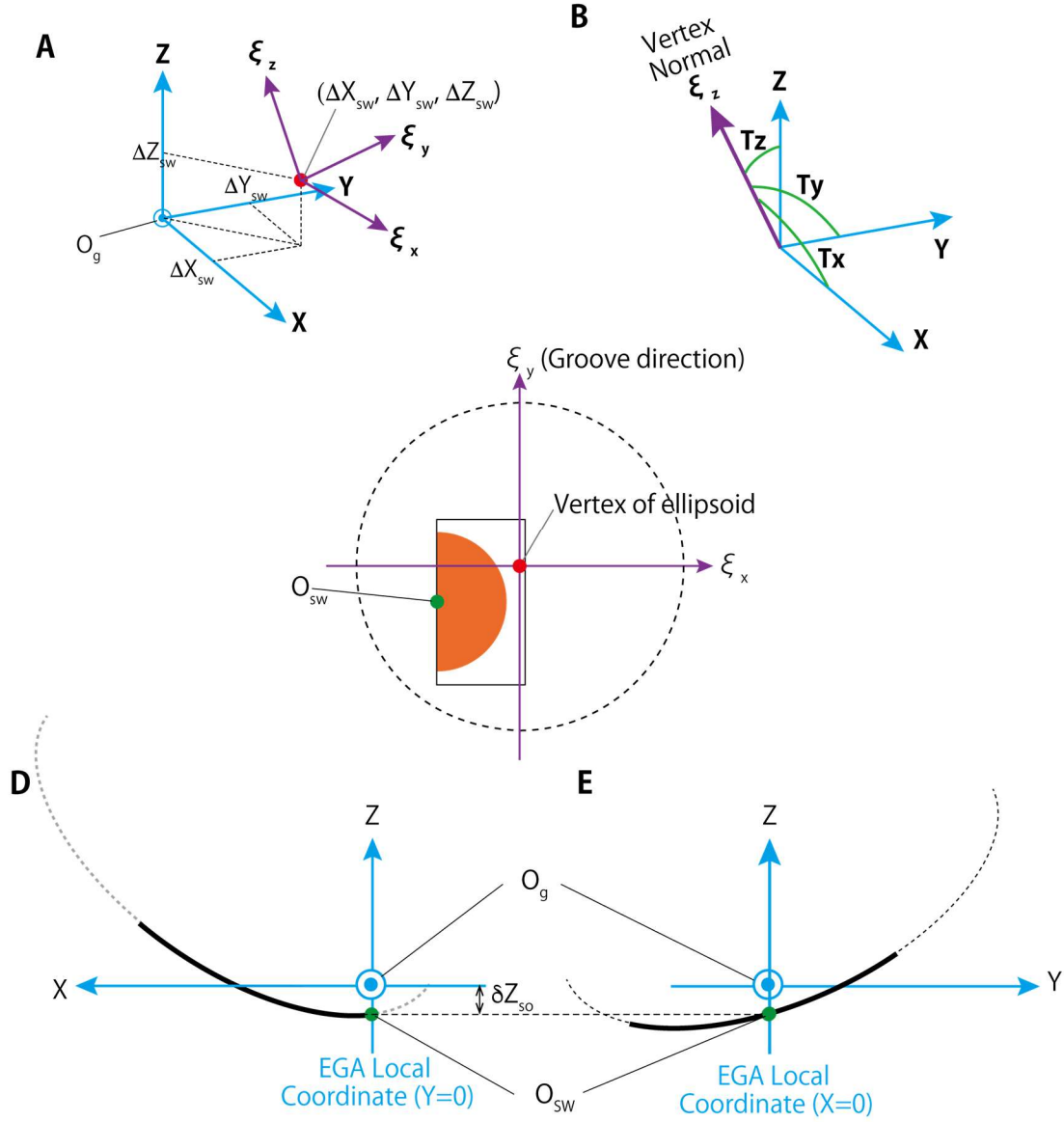


Figure 2. Panel A shows the relationship between the coordinate to define the optical surface of the SW grating (hereafter SW coordinate, purple arrows with ξ_x, ξ_y, ξ_z) and the EGA local coordinate (light blue arrows with X, Y, Z). The surface of the SW grating is a conic (ellipse), with the origin of the SW coordinate system located at the vertex of the ellipse (red points in panels A and C), and the normal to the surface at the vertex is defined as ξ_z . The origin of SW coordinate is deviated by $(\Delta X_{SW}, \Delta Y_{SW}, \Delta Z_{SW})$ with respect to the origin of the EGA local coordinate (O_g). Panel B shows the schematic of angles (T_x, T_y, T_z) of the vertex normal of the ellipsoid ξ_z with respect to the EGA local coordinate (X, Y, Z). Panel C shows the ellipse viewing from the $+\xi_z$ direction. The grooves are parallel to the ξ_y direction. Panels D and E show the schematics of the cross section of the ellipsoidal optical surface on the $Y=0$ and $X=0$ planes in the EGA local coordinate. The point on the ellipsoid at $X=Y=0$ is defined as O_{SW} (green point). The Z of O_{SW} is not zero but designed to be $\delta Z_{SO} \sim \delta Z_{LO}$ (Figure 2) to minimize the gap between LW and SW gratings. The position O_{SW} is at the middle in ξ_y direction and the end of the ξ_x direction on the substrate, and at the center of the semicircular useful area (orange semicircle in panel C). Note that the semicircular useful area is defined in the EGA local coordinate system.

4.1.1.2 Technical requirements for SW substrates (for information only)

No.	Item	Specification	Remarks
1. Grating for SW			
1-a	Substrate		
1-a-1	Substrate material	Fused silica	Corning C7980 0A
1-a-2	Form of substrate	Rectangular	See drawing on Figure 3 1
1-a-3	Grating Size (useful area)	Semicircle with 37 mm diameter (2 mm margin).	Centered on O_{sw} (green point in Erreur ! Source du renvoi introuvable.) (X, Y) = (0, 0) in the EGA coordinate system (ξ_x, ξ_y) = (-33.054, -15.315) in the SW coordinate system
1-a-4	Outer dimensions	See drawing on annexe 1 Accuracy on dimensions ± 0.2 mm Unless otherwise specified	Can be adapted based on optical fabrication constraints.
1-a-5	Thickness	20.0 ± 0.2 mm	Defined at point O_g Can be adapted based on optical fabrication constraints.
1-b	Optical Surface		
1-b-1	Shape of optical surface	Off-axis Ellipsoid	Conic surface defined by R & k
1-b-2	Position of ellipsoid vertex	$\Delta X_{SW} = +31.839 \pm 0.05$ mm $\Delta Y_{SW} = +15.070 \pm 0.2$ mm $\Delta Z_{SW} = +2.446 \pm 0.2$ mm	ΔX_{SW} is the most critical value as it is in the direction of the bond between the two halves. Location of the origin of the SW coordinate system (ξ_x, ξ_y, ξ_z) in the EGA local coordinate system. See panel A of Erreur ! Source du renvoi introuvable. Must be measured in the substrate reference system (i.e. wrt. reference sides D, E & F, annexe 1). i.e.: $\Delta X_{SW}' = +51.764$ mm $\Delta Y_{SW}' = +58.164$ mm $\Delta Z_{SW}' = +22.420$ mm
1-b-3	Radius of curvature & conic constant	$R = 516.027 \pm 1$ mm (ξ_z direction) (0.2%) $k = -0.523$	Precision has to be better than ± 1 mm with an objective of $\pm 0,25$ mm
1-b-4	Tilt of the normal axis of ellipsoid at vertex	Angles of the normal axis of ellipsoid at vertex (ξ_z) with respect to EGA local coordinate (See panel B of Figure 2 for definitions) $T_x = 95.08753 \pm 0.14^\circ$ $T_y = 93.13911 \pm 0.25^\circ$ $T_z = 5.98239^\circ$	$T_x = \cos^{-1}(\xi_z \cdot n_x)$ $T_y = \cos^{-1}(\xi_z \cdot n_y)$ $T_z = \cos^{-1}(\xi_z \cdot n_z)$ with n_x, n_y, n_z , the unit vector of the EGA local coordinate system. Must be measured wrt back face F. T_x and T_y are sufficient to define the orientation of the normal. T_z is given for reference. Uncertainty on T_x could be relaxed based on measured properties of glue.

			Since the EGA and the substrate system are parallel, the angles wrt reference sides are the same. Knowledge of T_x T_y will be $< 5''$
1-b-5	Ellipse roll	Angle between ξ_x and X axes: $\cos^{-1}(\xi_x \cdot n_x) = 5.09 \pm 0.5^\circ$	To be measured wrt side reference face D. Precision on the angle has to be better than $\pm 0.5^\circ$ with an objective of $\pm 0.25^\circ$
1-b-6	RMS figure error of the substrate (SFE)	2D PSD bounded by $2 \times 10^{10} \nu^{-3} \text{ nm}^4$ with ν the spatial frequency in mm^{-1} Equivalent to: $< 5 \text{ nm RMS over } [0.02, 4 \text{ mm}^{-1}]$ $< 0.4 \text{ nm RMS over } [2, 500 \text{ mm}^{-1}]$ (roughness)	At $\lambda = 632.8 \text{ nm}$. This is to be understood wrt. best fit conic (R, k). Full aperture measurements on a range of scales from 0.1 to 40 mm. Measurements at smaller scales can be on smaller representative areas. SFE has to be less than 5nm RMS over $[0.02, 4 \text{ mm}^{-1}]$ with an objective of 2,5 nm RMS or better SFE has to be less than 0,4 nm RMS over $[2, 500 \text{ mm}^{-1}]$ with an objective of 0,25 nm RMS or better
1-b-7	Surface quality	20/10 (MIL-O-13830)	
1-b-8	Fiducials	Three fiducials in the corners of the substrates at less than 5mm from the outer edges Three fiducials outside the useful area, less than 3 mm from the final edges	Corner fiducials defined in the substrates drawings (annexe 1). Exact position and shape of the inner fiducials to be approved by IAS at MRR
1-c	Non-optical surfaces		
1-c-1	Scratch & dig	40/20 (MIL-O-13830)	
1-c-2	Quality of back surface	Polished P3 3/3(1) $< \lambda / 10 \text{ RMS}$	At $\lambda = 632.8 \text{ nm}$, wrt. best plane Over a $> 2 \text{ cm}^2$ area. No WFE spec on the remainder of the back surface. Side F in annexe 1
1-c-3	Quality of reference side	Polished P1 $< \lambda / 10 \text{ RMS}$	At $\lambda = 632.8 \text{ nm}$, wrt best plane Over entire surface or $> 2 \text{ cm}^2$. Side E in annexe 1.
1-c-4	Quality of other sides	Grounded	
1-c-5	Perpendicularity of back surface & reference sides	$< 15'$	
1-c-6	Orientation of other sides	N/A	

Table 1. SW substrates technical specifications

4.1.2 SW grating ruling specifications

Grooves			
R-EGA-OPT-1401			
D	Line Spacing	Constant	
R-EGA-OPT-1402			
T	Groove density at vertex	4200 ± 2 lines/mm	
R-EGA-OPT-1403			
T	Groove Alignment	Angle: ± 15' wrt reference sides	
R-EGA-OPT-1404			
T	Groove profile	Laminar	
R-EGA-OPT-1405			
T	Groove direction	Along ξ_y axis	
R-EGA-OPT-1406			
T	Roughness	RMS roughness increase with respect to the substrates measured roughness < 0.1 nm	
R-EGA-OPT-1407			
S	Efficiency	> 35% over [17 – 21.5 nm] for TE & TM	Groove efficiency
R-EGA-OPT-1408			
T	Ruled area dimensions	Over the useful area defined in 1-a-3 (4.1.1.2)	
R-EGA-OPT-1409			
T	Radius of curvature	The relative change of radius of curvature as a result of the etching process shall be < 1e-5	
R-EGA-OPT-1410			
T	0th order WFE	The delta WFE with respect the substrates measured WFE shall be < 0.2 nm RMS, 1 nm PV	Wrt. best fit conic (R, k). Full aperture measurements on scales from 0.1 to 40 mm.

Table 2. SW grating ruling requirements

Le profil exact des traits sera proposé par le titulaire et validé par l'IAS lors de la MRR, 1 mois après la réunion de démarrage (voir chapitre 5.4.2)

The exact groove profile will be a technical proposal from the vendor, validated by IAS during the MRR, one month after the kick off meeting (see chapter 5.4.2)

4.1.3 SW final shape and dimensions requirements

4.1.3.1 Grating final shape

La forme rectangulaire des substrats a été choisie afin d'avoir une marge confortable autour de la zone utile lors de l'enregistrement des traits constituant le réseau.

Cependant la forme finale des réseaux est octogonale, l'annexe 3 donne le plan du réseau SW comprenant les côtes tolérancées.

Il est demandé au titulaire de réaliser la découpe des substrats gravés aux dimensions finales demandées.

Les spécifications d'état de surface pour les faces non optiques sont les suivantes

The substrates have a rectangular shape in order to have sufficient margin around the useful area during the holographic ruling.

But the final shape of the gratings is octagonal. The drawing in annexe 3 is the drawing of the SW final shape with tolerances on dimensions.

The requirement on the non-optical surfaces are given in the table below

Non-optical surfaces			
R-EGA-OPT-1301			
I	Scratch & dig	40/20 (MIL-O-13830)	
R-EGA-OPT-1302			
T	Quality of back surface	Polished P3 3/3(1) < λ / 10 RMS	For reference. The back surface is provided polished and should not be modified. Side F in annexe 3 and Figure 6.
R-EGA-OPT-1303			
T	Quality of reference side	Polished P1 < λ / 10 RMS	At $\lambda = 632.8\text{nm}$, wrt best plane Over the entire surface or >2 cm ² . Side E in annexe 3 and Figure 6.
R-EGA-OPT-1304			
I	Quality of other sides	Grounded	
R-EGA-OPT-1305			
T	Quality of contact side	Polished	Side D in Figure 3 3 and Figure 6.
R-EGA-OPT-1306			
T	Perpendicularity of back surface & reference sides	< 15' (knowledge \pm 10'')	
R-EGA-OPT-1307			
T	Parallelism of reference sides wrt substrate reference sides	< 1'	
R-EGA-OPT-1308			
	Orientation of other sides	N/A	
R-EGA-OPT-1309			
T	Angles of contact surface wrt back and reference sides	< 15' (knowledge \pm 10'')	
R-EGA-OPT-1310			
I	Serial number	Engraved # (SW1, SW2, SW3, ...) on a non-reference side, not on the contact side.	Details can be discussed at MRR
R-EGA-OPT-1311			
T	Chamfers	Flat 45° 0.5 mm wide	On all 90° edges

Table 3 non-optical surfaces requirements for SW gratings after final shape cutting

Figure 3 SW grating final shape and dimensions, with reference sides labelled

4.2 LOT 2 : LW gratings

4.2.1 LW Substrate definition (for information)

Le plan de fabrication des substrats LW est donné en annexe 2

The manufacturing plans of the LW substrates is given in annexe 2

4.2.1.1 LW substrate axis definition

Figure 4 **Erreur ! Source du renvoi introuvable.** shows the relationship between the EGA local coordinates (section 3) and the coordinates that define the optical surfaces of LW (η_x , η_y , η_z), called the LW coordinate system.

The conversion between the LW coordinate and EGA local coordinate is given as follows:

$$\begin{aligned}\eta_x &= 0.999909 X + 0.000082 Y - 0.013497 Z - 0.000166 \\ \eta_y &= 0.000000 X + 0.999982 Y + 0.006048 Z - 2.038603 \\ \eta_z &= 0.013497 X - 0.006047 Y + 0.999891 Z + 0.012328\end{aligned}$$

The inverse conversion between the EGA coordinate and LW coordinate is given as follows:

$$\begin{aligned}X &= 0.999909 \eta_x - 0.000000 \eta_y + 0.013497 \eta_z - 0.000000 \\ Y &= 0.000082 \eta_x + 0.999982 \eta_y - 0.006047 \eta_z + 2.038640 \\ Z &= -0.013497 \eta_x + 0.006048 \eta_y + 0.999891 \eta_z - 0.000000\end{aligned}$$

We also define the coordinate system defined by the three planes corresponding to the three reference sides of the substrate (see **Erreur ! Source du renvoi introuvable.**annexe 2 and annexe 4). This system is called the substrate coordinate system.

LW Grating

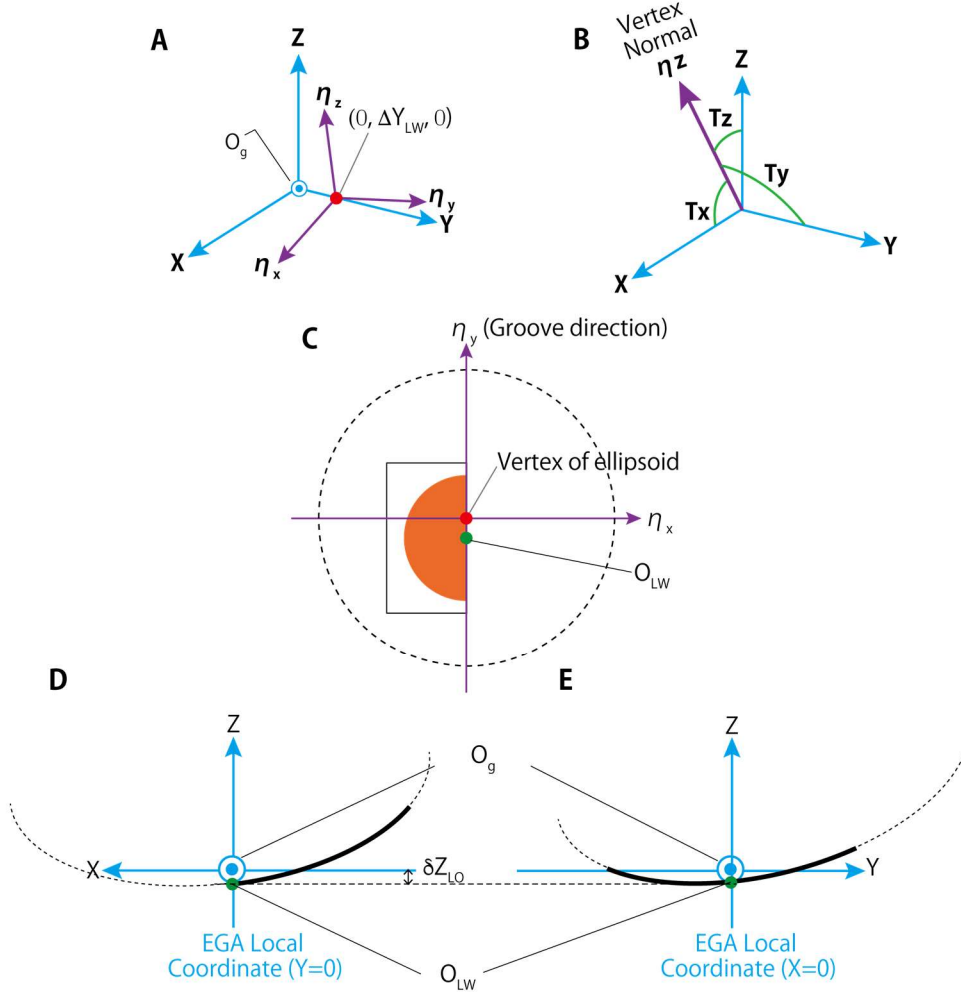


Figure 4 Panel A shows the relationship between the coordinate to define the optical surface of the LW grating (hereafter LW coordinate, purple arrows with η_x, η_y, η_z) and the EGA local coordinate (light blue arrows with X, Y, Z). The ellipsoid of LW grating is defined as $\eta_x^2/R_1^2 + \eta_y^2/R_2^2 + (\eta_z - R_3)^2/R_3^2 = 1$, meaning that the origin of LW coordinate is located at the vertex of the ellipsoid (red points in panels A and B) and that the normal axis of the ellipsoid at the vertex is defined as η_z . The origin of LW coordinate is deviated by $(\Delta X_{LW}=0, \Delta Y_{LW}, \Delta Z_{LW}=0)$ with respect to the origin of the EGA local coordinate (O_g). Panel B shows the schematic of angles (T_x, T_y, T_z) of the vertex normal of the ellipsoid η_z with respect to the EGA local coordinate (X, Y, Z) . Panel C shows the ellipsoid viewing from the $+\eta_z$ direction. The grooves are parallel to the η_y direction. Panels D and E show the schematics of the ellipsoidal optical surfaces on the $Y=0$ and $X=0$ planes in the EGA local coordinate. The point on the ellipsoid at $X=Y=0$ is defined as O_{LW} (green point). The Z location of O_{LW} is not zero but the same as O_{SW} (Figure 1). The position O_{LW} is at the middle in η_y direction and the end of the η_x direction on the substrate, and at the center of the semicircular useful area (orange semicircle in panel C). Note that the semicircular useful area is defined in the EGA local coordinate system.

4.2.1.2 Technical requirements for LW substrate (for information)

No.	Item	Specification	Remark
2. Grating for LW			
2-a	Substrate		
2-a-1	Substrate material	Fused silica	Corning C7980 0A
2-a-2	Form of substrate	Rectangular	See drawing in annexe 1.
2-a-3	Grating Size (useful area)	Semicircle with 37 mm diameter (2 mm edge margin)	Centered on O_{LW} (green point in Figure 4) (X, Y) = (0, 0) in the EGA coordinate system (η_x , η_y) = (0.000, -2.039) in the LW coordinate system.
2-a-4	Outer dimensions	See drawing on Erreur ! Source du renvoi introuvable. Accuracy on dimensions ± 0.2 mm Unless otherwise specified	Can be adapted based on optical fabrication constraints.
2-a-5	Thickness	20.0 ± 0.2 mm	Defined at point O_g . Can be adapted based on optical fabrication constraints.
2-b	Optical Surfaces		
2-b-1	Shape of optical surface	Off-axis Ellipsoid	Generalized ellipsoid defined with two semi-axes (R_1 , R_2) and one radius of curvature (R_3) defined as $\eta_x^2/R_1^2 + \eta_y^2/R_2^2 + (\eta_z - R_3)^2/R_3^2 = 1$.
2-b-2	Position of Ellipsoid vertex	$\Delta X_{LW} = 0.000 \pm 0.2$ mm $\Delta Y_{LW} = +2.039 \pm 0.2$ mm $\Delta Z_{LW} = 0.000 \pm 0.2$ mm	ΔX_{SW} is the most critical value as it is in the direction of the bond between the two halves. Location of the origin of the LW coordinate system (η_x - η_y - η_z) in the EGA local coordinate system. See panel A of Figure 4. The coordinates in the substrate reference system (i.e. wrt. reference sides G, B & C in annexe 4.) are: $\Delta X_{LW}' = 42.000$ mm $\Delta Y_{LW}' = 45.133$ mm $\Delta Z_{LW}' = 20.000$ mm
2-b-3	Semi-axes (R_1 , R_2) and radius of curvature (R_3) of ellipsoid surface	$R_1 = 1008.955$ mm (η_x direction) $R_2 = 1010.281$ mm (η_y direction) $R_3 = 1933.255 \pm 1$ mm (η_z direction) (0.05%)	Precision on R_3 has to be better than ± 1 mm
2-b-4	Tilt of the normal axis of ellipsoid at vertex	Angles of the normal axis of ellipsoid at vertex (η_z) with respect to EGA local coordinate (See panel B of Figure 4 for definitions) $T_x = 89.2267 \pm 0.14^\circ$ $T_y = 90.3465 \pm 0.25^\circ$ $T_z = 0.8474^\circ$	$T_x = \cos^{-1}(\xi_z \cdot n_x)$ $T_y = \cos^{-1}(\xi_z \cdot n_y)$ $T_z = \cos^{-1}(\xi_z \cdot n_z)$ with n_x, n_y, n_z , the unit vector of the EGA local coordinate system. Must be measured wrt. back surface C. T_x and T_y are sufficient to define the orientation of the normal. T_z is given for reference.

			<p>Uncertainty on T_x could be relaxed based on measured properties of glue.</p> <p>Since the EGA and the substrate system are parallel, the angles wrt. reference sides are the same.</p> <p>Knowledge T_x T_y of will be $< 5''$</p>
2-b-5	Ellipse roll	<p>Angle between η_x and X axes: $\cos^{-1}(\eta_x \cdot n_x) = 0.77 \pm 0.5^\circ$</p>	<p>To be measured wrt. side reference face B.</p> <p>Precision on the angle has to be better than $\pm 0.5^\circ$ with an objective of $\pm 0.25^\circ$</p>
2-b-6	RMS figure error of the substrate (SFE)	<p>2D PSD bounded by $2 \times 10^{10} \nu^{-3} \text{ nm}^4$ with ν the spatial frequency in mm^{-1} Equivalent to: $< 5 \text{ nm RMS over } [0.02, 4 \text{ mm}^{-1}]$ $< 0.4 \text{ nm RMS over } [2, 500 \text{ mm}^{-1}]$ (roughness)</p>	<p>At $\lambda = 632.8 \text{ nm}$. This is to be understood wrt best fit ellipsoid. The accuracy of the ellipsoid main radius is specified independently (see 2-b-3). Full aperture measurements on a range of scales from 0.1 to 40 mm. Measurements at smaller scales can be on smaller representative areas. SFE has to be less than 5 nm RMS over $[0.02, 4 \text{ mm}^{-1}]$ with an objective of 2.5 nm RMS or better</p> <p>SFE has to be less than 0.4 nm RMS over $[2, 500 \text{ mm}^{-1}]$ with an objective of 0.25 nm RMS or better</p>
2-b-7	Surface quality	20/10 (MIL-O-13830)	
2-b-8	Fiducials	<p>Three fiducials in the corners of the substrates at less than 5 mm from the outer edges</p> <p>Three fiducials outside the useful area, less than 3 mm from the final edges</p>	Exact position and shape to be approved by IAS at MRR
2-c	Non-optical surfaces		
2-c-1	Scratch & dig	40/20 (MIL-O-13830)	
2-c-2	Quality of back surface	<p>Polished P3 3/0.25(0.25) $< \lambda / 15 \text{ RMS}$ $< 0.5 \text{ nm rms roughness}$</p>	<p>At $\lambda = 632.8 \text{ nm}$, wrt. best plane Over a $> 2 \text{ cm}^2$ area. No WFE spec on the remainder of the back surface.</p> <p>Side C in annexe 2 and annexe 4. Roughness measurements in the range $[1 \mu\text{m} - 1 \text{ mm}]$</p>
2-c-3	Quality of reference sides	<p>Polished P1 $< \lambda / 10 \text{ RMS}$</p>	<p>At $\lambda = 632.8 \text{ nm}$, wrt. best plane Over entire surface or $> 2 \text{ cm}^2$. Sides B & G in annexe 2 and annexe 4.</p>
2-c-4	Quality of other sides	Grounded	

2-c-5	Perpendicularity of back surface & reference sides	< 15°	
2-c-6	Orientation of other sides	N/A	

Table 4 LW substrates technical requirements

4.2.2 LW grating ruling specifications

R-EGA-OPT-2401					
D	Line Spacing	Variable			
R-EGA-OPT-2402					
T	Groove density at vertex	1740 ± 1 lines/mm			
R-EGA-OPT-2403					
D	Law groove density	Zemax parameters: $\alpha = -7.2998139 \times 10^{-5} \pm 7.298e-7$ (±1%) $1/T = 1/1.74 - \alpha \eta_x$ $(-18.5 \leq \eta_x \text{ (mm)} \leq 0)$			
R-EGA-OPT-2404					
T	Groove Alignment	Angle: ± 15' wrt reference sides Translation: ± 0.5 mm wrt reference side	± 0.5 mm corresponds to a groove error of ± 0.2 lines/mm		
R-EGA-OPT-2405					
T	Groove profile	Blazed	Exact profile to be a proposition by the vendor		
R-EGA-OPT-2406					
T	Groove direction	Along η_y axis			
R-EGA-OPT-2407					
T	Roughness	RMS roughness increase with respect to the substrates measured roughness < 0.1 nm			
R-EGA-OPT-2408					
S	efficiency	λ [nm]	Efficiency [%]		Groove efficiency
			TE	TM	
		70	34.2	30.6	
		75	49.5	44.1	
		80	60.3	55.8	
		85	65.7	64.8	
		90	71.1	72.0	
		95	72.9	76.5	
		100	73.8	77.4	
		105	72.9	77.4	
		110	71.1	76.5	
		115	68.4	75.6	
		120	65.7	74.7	
		125	63.0	73.8	
R-EGA-OPT-2409					
T	Ruled area dimensions	Over the useful area defined in 2-a-3 (4.2.1.1)			
R-EGA-OPT-2410					

T	Radius of curvature	The relative change of radius of curvature as a result of the etching process shall be $< 1e-5$	
R-EGA-OPT-2411			
T	Oth order WFE	The delta WFE with respect the substrates measured WFE shall be < 0.2 nm RMS, 1 nm PV	Wrt. best fit conic (R, k). Full aperture measurements scales from 0.1 to 40 mm

Table 5 LW grating ruling requirements

Le profil exact des traits sera proposé par le titulaire et validé par l'IAS lors de la MRR, 1 mois après la réunion de démarrage (voir chapitre 5.4.2)

The exact groove profile will be a technical proposal from the vendor, validated by IAS during the MRR, one month after the kick off meeting (see chapter 5.4.2)

4.2.3 LW final shape and dimensions requirements

4.2.3.1 Grating final shape

La forme rectangulaire des substrats a été choisie afin d'avoir une marge confortable autour de la zone utile lors de l'enregistrement des traits constituant le réseau.

Cependant la forme finale des réseaux est octogonale, l'annexe 4 donne le plan du réseau LW comprenant les côtes tolérancées.

Il est demandé au titulaire de réaliser la découpe des substrats gravés aux dimensions finales demandées.

Les spécifications d'état de surface pour les faces non optiques sont les suivantes

The substrates have a rectangular shape in order to have sufficient margin around the useful area during the holographic ruling.

But the final shape of the gratings is octagonal. Annexe 4 is the drawing of the LW grating final shape with tolerances on dimensions.

The requirement on the non optical surfaces are given in the table below :

Non-optical surfaces			
R-EGA-OPT-2301			
I	Scratch & dig	40/20 (MIL-O-13830)	
R-EGA-OPT-2302			
T	Quality of back surface	Polished P3 3/0.25(0.25) $< \lambda / 15$ RMS < 0.5 nm rms roughness	At $\lambda = 632.8$ nm, wrt. best plane Over a > 2 cm ² area. For reference. The back-surface face is provided polished and should not be modified. Side C in annexe 4 and Figure 5
R-EGA-OPT-2303			
T	Quality of reference sides	Polished P1 $< \lambda / 10$ RMS	At $\lambda = 632.8$ nm, wrt best plane Over the entire surface or > 2 cm ² . Sides B & G in annexe 4 and Figure 5

R-EGA-OPT-2304			
I	Quality of other sides	Grounded	
R-EGA-OPT-2305			
T	Quality of contact side	Polished	Side A in annexe 4 and Figure 5
R-EGA-OPT-2306			
T	Perpendicularity of back surface & reference sides	< 15' (knowledge $\pm 10''$)	
R-EGA-OPT-2307			
T	Parallelism of reference sides wrt substrate reference sides	< 1'	
R-EGA-OPT-2307			
	Orientation of other sides	N/A	
R-EGA-OPT-2308			
T	Angles of contact surface wrt back and reference sides	< 15' (knowledge $\pm 10''$)	
R-EGA-OPT-2309			
I	Serial number	Engraved # (LW1, LW2, LW3, ...) on a non-reference side, not on the contact side.	Details can be discussed at MRR
R-EGA-OPT-2310			
I	Chamfers	Flat 45° 0.5 mm wide	On all 90° edges

Table 6 LW non- optical surfaces requirements after final shape cutting

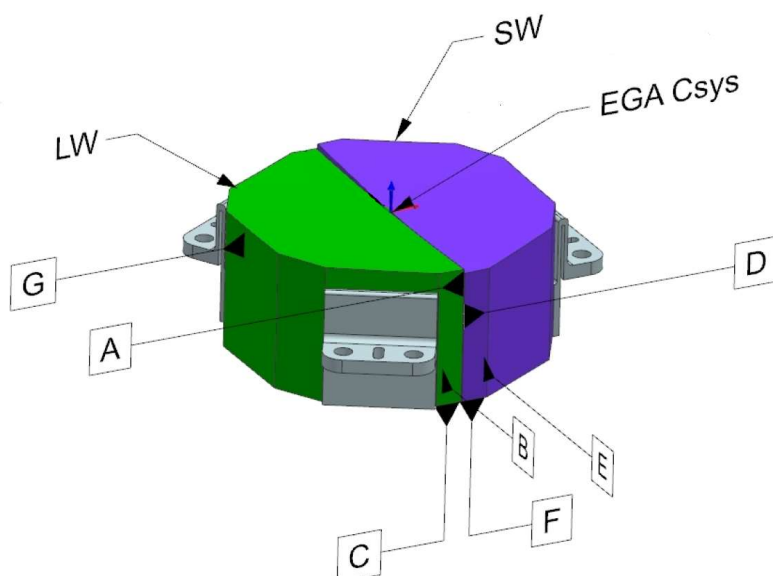


Figure 5 3D view showing SW grating in purple and LW grating in green, with identification of the non-optical surfaces

The pieces shall be packed and labelled in order to be clearly identified as being cut out from which particular grating.

Only parts with dimension $> 10\text{mm}$ in diameter (or $10\text{mm} \times 10\text{mm}$) are requested.

5 General requirements - Applicable lot 1 & lot 2

5.1 Fiducials

Des marques fiduciaires repérant l'orientation de la surface optique sur le réseau dans sa forme finale doivent être réalisés par le titulaire.

Ces marques doivent se situer en dehors de la zone utile tel qu'indiqué sur la Figure 6.

La forme exacte des marques fiduciaire et la façon de les réaliser doit être validé par l'IAS sur proposition du titulaire lors de la validation des plans de fabrication des réseaux sous leur forme finale, au plus tard lors de la revue intermédiaire (voir chapitre 5.4.2)

Fiducial marks shall be made on the optical surface outside the useful area in order to represent the orientation of the optical surface axis as shown in Figure 6.

The exact nature and position of the fiducial marks is to be agreed by IAS upon proposal by the vendor at the latest during the intermediate review (see chapter 5.4.2).

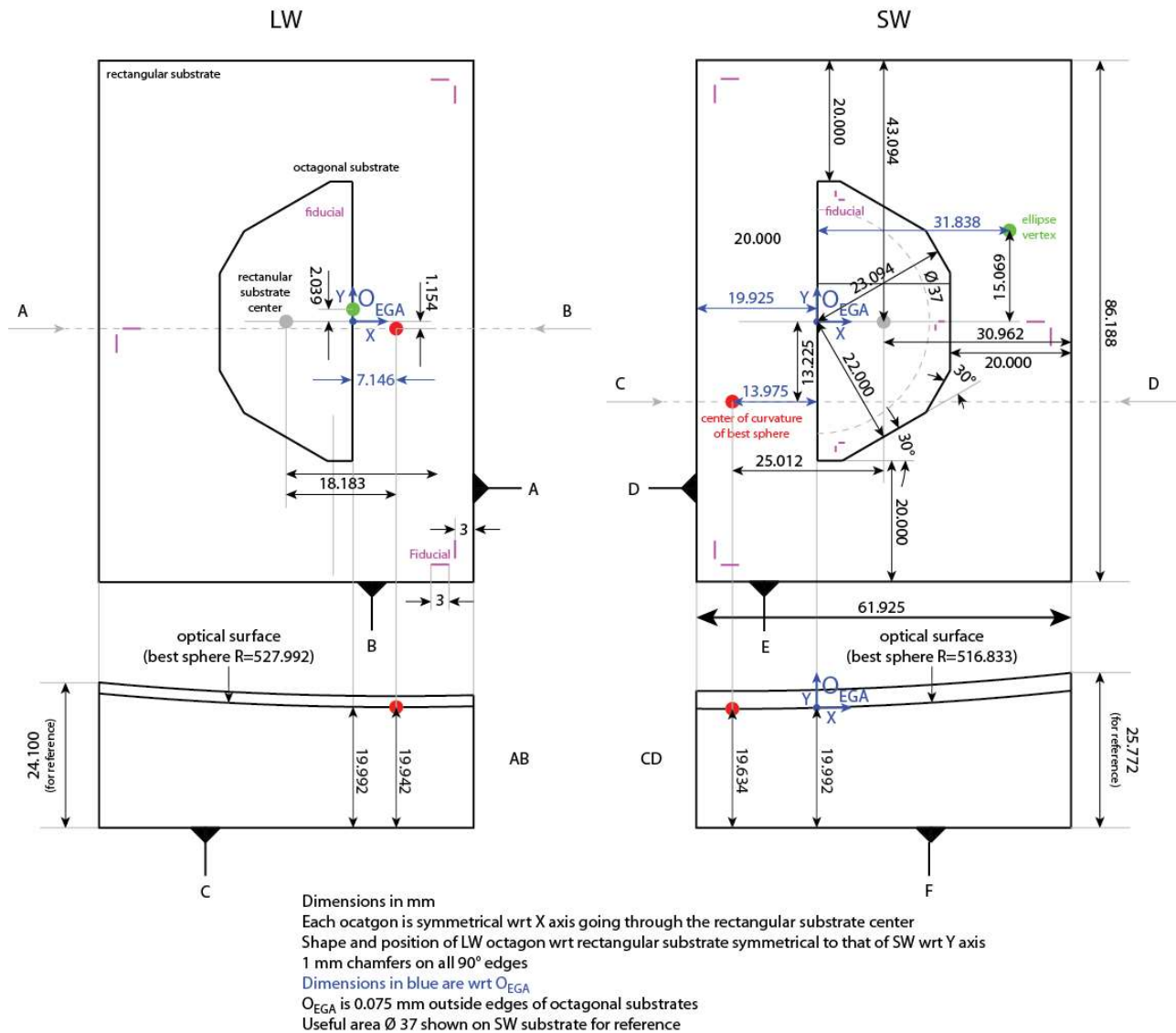


Figure 6 fiducial position on SW and LW substrates and gratings

5.2 Witness samples

L'IAS demande à récupérer les chutes de découpage des réseaux afin de servir d'échantillons témoins de la gravure.

Les morceaux doivent être emballés et étiquetés de façon à pouvoir identifier de quel réseau final ils sont issus.

Seuls les morceaux de dimensions supérieures à 10mm de diamètre ou 10mm x 10mm de côté sont demandés.

In lieu of witness samples, IAS requests that the residual pieces of the cutting of the rectangular gratings to their final octagonal shape shall be delivered to IAS

The pieces shall be packed and labelled in order to be clearly identified as being cut out from which particular grating.

Only parts with dimension $> 10\text{mm}$ in diameter (or $10\text{mm} \times 10\text{mm}$) are requested.

5.3 Tests

R-VM-1 Verification The verification method associated with each technical requirement is stated in the verification matrix.

Pour chaque spécification technique la méthode de vérification devra être indiquée dans la matrice de conformité.

5.4 Product assurance and quality assurance

5.4.1 General requirements

R-PA-1 Language documentation shall be established in English, with use of metric system (International System of Units).

Toute la documentation doit être écrite en anglais, l'utilisation du système métrique est demandée

R-PA-2 Change Requests changes after completion of the Manufacturing Readiness Review (MRR) shall be agreed between IAS team & supplier through a Change Request (CR).

Toutes modifications demandées après la MRR (revue préalable à l'accord pour fabrication) doivent être acceptées par l'IAS et le titulaire et documenté sous la forme d'un change request (demande de modification)

R-PA-3 Non-Conformities Final items discrepancy with respect to agreed drawings and requirements shall be traced through NCR (Non-Compliance report). NCR affecting performance, interfaces, interchangeability shall be considered as major and notified to IAS team. Final dispositions (scrap, rework, use-as-is, waiver) shall be agreed between IAS team and the supplier before they are implemented.

Les différences entre le produit fini et les spécifications et dessins techniques validés doivent être tracées par des rapports de non-conformité (NCR). Les NCR qui ont des conséquences sur les performances, les interfaces et l'interchangeabilité des différents composants sont considérées comme majeures et doivent être notifiées à l'IAS dès leur découverte. Les disposition finales (inutilisable, réparable, utilisable tel que, dérogation) seront à discuter et valider entre l'IAS et le titulaire sélectionné avant mise en place le cas échéant.

R-PA-4 Traceability. Each optical element shall be unequivocally identified with a serial number engraved on one non-reference surface. For example LW1, LW2, LW3, SW1, SW2, SW3

Traçabilité : chaque composant optique doit être identifié de façon non équivoque avec un numéro de série sur une des faces non optiques. Ce numéro peut par exemple être LW1, LW2, LW3, SW1, SW2, SW3

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5.4.2 Meetings, Reviews, inspections and key points

R-PA-5 Meetings Monthly progress meetings will be held via teleconference (or in person at the request of one of the parties) to report the progress of the manufacturing.

Des réunions mensuelles d'avancement seront organisées via téléconférence (ou en personne si l'une des parties le demande)

R-PA-6 Reviews Several reviews will be held during the manufacturing program. The sequence and purpose of these reviews are given in the table below

Two type of dates are indicated in the table expected dates and maximum acceptable dates

T0 is when the contract is notified to the supplier

Plusieurs revues seront organisées pendant la durée de fabrication des substrats, leur séquence et objectifs principaux sont indiqués dans les tableaux ci-dessous

Deux types de délais sont indiqués, les délais souhaités et les délais maximum acceptables.

T0 est le jour de la notification du marché

Planning lot 1

Review	When		Purpose
Kick-off Démarrage	Beginning of program Début du contrat	T0 + 1 week T0 + 1 semaine	Obtain common understanding of IAS need & requirements Obtain general flow chart of manufacturing and metrology processes Se mettre d'accord sur les besoins de l'IAS et les spécifications Etablir un diagramme de planification des différentes activités et procédures de la fabrication et de la métrologie des réseaux
MRR Manufacturing Readiness Review Revue de préalable à l'accord pour fabrication	Before first manufacturing step Avant le début de la fabricationT0	T0 + 4 weeks T0 + 4 semaines	Grant authorization for manufacturing. Minor changes to the specifications can still occur up to this meeting. Donner l'autorisation de démarrer la fabrication de l'outillage. Des changements mineurs des spécifications peuvent intervenir jusqu'à cette revue

			Minutes de réunion à l'issue
IIR first 2 SW substrates <i>Inspection d'entrée des deux premier substrats SW</i>	After shipment of the first 2 SW substrates by IAS to the vendor <i>Après envoi deux premiers substrats SW par l'IAS au titulaire</i>	April 2025 <i>Avril 2025</i>	Substrates responsibility is transferred to the vendor <i>Transfert de la responsabilité des substrats vers le titulaire</i>
Intermediate review <i>Revue intermédiaire</i>	After SW grating ruling but before cutting the grating to their final dimensions <i>Après la gravure des réseaux SW et avant la découpe à la forme finale</i>	T0 + 44 weeks expected <i>T0 + 44 semaines souhaité</i>	Confirms the compliance of the grating profile Validation of the manufacturing plan for the gratings in their final shape Granting authorization for cutting the gratings to their final shape <i>Valide le profil de la gravure effectué, valide le plan de fabrication final des réseaux et donne l'autorisation de découper les réseaux à la forme finale</i>
AR Acceptance Review for SW gratings <i>Revue d'acceptance pour les réseaux SW</i>	Before formal delivery of the SW grating <i>Avant la livraison formelle des réseaux SW</i>	T0 + 66 weeks expected <i>T0 + 66 semaines souhaité</i>	Grant acceptance of manufactured items @supplier by review of documentation <i>Donner l'autorisation de livrer les réseaux SW après revue de la documentation fournie par le titulaire</i>
Delivery SW gratings 3 models (minimum number, of ruled and cut to final shape gratings), residual		T0 + 66 weeks expected (70 weeks max)	

pieces from cutting and unused substrates if any Livraison des réseaux SW (3 modèles gravés découpé minimum), des chutes et des substrats non utilisés le cas échéant, 5 au maximum)		T0 + 66 semaines souhaité (70 semaines max)	
IIR SW Revue d'inspection d'entrée à la livraison des réseaux SW	Incoming inspection review Inspection à la livraison	T0 + 70 weeks expected (74 weeks max) T0 + 70 semaines souhaité (74 semaines max)	Inspection and metrology check made @IAS upon delivery of SW gratings Inspection et vérification de la métrologie effectuée par l'IAS à la livraison des réseaux SW

Tableau 1 **planning des revues lot 1** – review schedule for Lot 1

PLANNING LOT 2

Review	When		Purpose
Kick-off Démarrage	Beginning of program Début du contrat	T0 + 1 week T0 + 1 semaine	Obtain common understanding of IAS need & requirements Obtain general flow chart of manufacturing and metrology processes Se mettre d'accord sur les besoins de l'IAS et les spécifications Etablir un diagramme de planification des différentes activités et procédures de la fabrication et de la métrologie des réseaux

MRR Manufacturing Readiness Review Revue de préalable à l'accord pour fabrication	Before first manufacturing step Avant le début de la fabrication T0	T0 + 4 weeks T0 + 4 semaines	Grant authorization for manufacturing. Minor changes to the specifications can still occur up to this meeting. Donner l'autorisation de démarrer la fabrication de l'outillage. Des changements mineurs des spécifications peuvent intervenir jusqu'à cette revue Minutes de réunion à l'issue
IIR first L SW substrates Inspection d'entrée des deux premier substrats LW	After shipment of the first 2 LW substrates by IAS to the vendor Après l'envoi deux premiers substrats LW par l'IAS au titulaire	mai 2025 mai 2025	Substrates responsibility is transferred to the vendor Transfert de la responsabilité des substrats vers le titulaire
Intermediate review LW Revue intermédiaire LW	After grating ruling but before cutting the grating to their final dimensions Après la gravure du réseau et avant la découpe à la forme finale	T0 + 80 weeks expected T0 + 80 semaines souhaité	Confirms the compliance of the grating profile Validation of the manufacturing plan for the gratings in their final shape Granting authorization for cutting the gratings to their final shape Valide le profil de la gravure effectué, valide le plan de fabrication final des réseaux et donne l'autorisation de découper les réseaux à la forme finale

AR Acceptance Review for LW gratings <i>Revue d'acceptance pour les réseaux LW</i>	Before formal delivery of the LW grating <i>Avant la livraison formelle des réseaux LW</i>	T0 + 100 weeks expected <i>T0 + 100 semaines souhaité</i>	Grant acceptance of manufactured items @supplier by review of documentation <i>Donner l'autorisation de livrer les réseaux LW après revue de la documentation fournie par le titulaire</i>
Delivery LW gratings 3 models (minimum number, of ruled and cut to final shape gratings), residual pieces from cutting and unused substrates if any <i>Livraison des réseaux LW (3 modèles gravés découpé minimum), des chutes et des substrats non utilisés le cas échéant, 5 au maximum)</i>		T0 + 100 weeks expected (104 weeks max) <i>T0 + 100 semaines souhaité (104 semaines max)</i>	
IIR LW <i>Revue d'inspection d'entrée à la livraison des réseaux LW</i>	Incoming inspection review <i>Inspection à la livraison</i>	T0 + 104 weeks expected (108 weeks max) <i>T0 + 104 semaines souhaité (108 semaines max)</i>	Inspection and metrology check made @IAS upon delivery of LW gratings <i>Inspection et vérification de la métrologie effectuée par l'IAS à la livraison des réseaux LW</i>

Tableau 2 *planning des revues lot 2 – review schedule for Lot 2*

R-PA-7 Key points. Key points will be arranged in agreement with both parties when an important step in the development has been achieved and documentation is available to be reviewed.

Key points will be agreed during kick off meeting.

Points Clef : l'IAS et le titulaire se mettront d'accord pour organiser des points clefs à chaque étape importante de la fabrication ou quand de la documentation importante est disponible pour être revue

L'organisation des points clefs sera validée lors de la réunion de kick off

5.4.3 Handling, cleaning, packing and shipping

R-PA-8 Handling and cleaning procedure

The supplier shall provide a handling and cleaning procedure for the gratings

A la livraison, le titulaire doit fournir une procédure manipulation et de nettoyage pour les réseaux

R-PA-9 Packing

All optical element shall be packed individually with the identification number of the component clearly shown on the package.

There should be no contact between the packaging and the optical useful surface.

The packaging shall be compatible with class ISO 5 clean room.

Tous les composants optiques doivent être emballés individuellement avec leur numéro de série clairement indiqué sur l'emballage.

L'emballage doit être tel qu'il n'y a pas de contact entre l'emballage et la surface optique utile

L'emballage doit être compatible avec une utilisation en salle propre de classe ISO 5

6 Delivery

6.1 Deliverables

6.1.1 Hardware

6.1.1.1 Lot 1

SW gratings: **quantity 3**

Cut out pieces of SW gratings

All remaining SW substrates shall be returned to IAS

Réseaux SW quantité : 3

Chutes de découpe des réseaux SW

Tous les substrats SW non utilisés doivent être retournés à l'IAS

6.1.1.2 Lot 2

LW gratings: **quantity 3**

Cut out pieces of LW gratings

All remaining LW substrates shall be returned to IAS

Réseaux LW quantité : 3

Chutes de découpe des réseaux LW

Tous les substrats LW non utilisés doivent être retournés à l'IAS

6.1.2 Documentation

Document	Comment
Packing/ Unpacking / Handling / Cleaning and Storage instructions Instructions d'emballage, déballage, manipulation, nettoyage et stockage	Common for all items Commun pour toutes les pièces
Metrology report Rapport de métrologie	One for each component Un par pièce Includes all dimensional measurements and tests results

	Doit inclure tous les résultats de mesures métrologiques et tests effectués
NCR Rapport de non conformité	If any, associated with the relevant component Associé à la pièce concernée le cas échéant
As manufactured compliance matrix Matrice de conformité après fabrication	One for each component Un par pièce

Documentation shall be delivered by the supplier 1 week prior to the reviews (MRR and ARs).

La documentation doit être livrée par le titulaire 1 semaine avant la date prévue des revues :
Revue de préalable à l'accord pour fabrication MRR et les Revues d'acceptance.

6.2 Delivery procedure

After acceptance of the formal delivery of the gratings during the acceptance review the supplier sends the optical elements along with the associated documentation packages.

Shipment and custom charges are paid for by the supplier.

Upon reception, IAS team will perform an incoming inspection. The incoming inspection report will be shared with the supplier.

IAS can take up to 4 weeks to perform the inspection

If no issue is found then the gratings are accepted and the final payment is made

If an issue is found, it is treated as a non-conformity and dealt with as per R-PA-3

Après avoir reçu l'accord formel pour la livraison des substrats lors de la revue d'acceptance, le titulaire doit envoyer les substrats avec la documentation associée.

Les frais de livraison et de douane sont à la charge du titulaire

A réception des éléments, l'IAS procède à une inspection d'entrée qui peut prendre jusqu'à 4 semaines.

Si aucun problème n'est identifié alors les réseaux sont formellement acceptés et le paiement final est autorisé

Si un problème est identifié par l'IAS alors il est traité via un rapport de non-conformité comme indiqué dans R-PA-3

6.3 Delivery address

Delivery shall be made at:

L'adresse de livraison est :

IAS – CNRS

Bâtiment 121 université Paris Saclay



Rue Jean Teillac

91400 Orsay FRANCE