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The ALBA high-stability monochromator for VUV and soft X-rays

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The ALBA high-stability monochromator for VUV and soft X-rays

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Abstract. LOREA is ALBA's beamline devoted to the investigation of solids electronic structure by means of Angle Resolved Photo-Emission Spectroscopy (ARPES). The beamline operates in the photon energy range 10-1000 eV with tuneable linear and circular polarizations produced by an APPLE II helical undulator. Thanks to its energy range and the high photon flux, LOREA is suitable for high resolution VUV ARPES investigations in the 10-200 eV range, while it is feasible to extend ARPES measurements to the 200-600 eV energy range (soft X-ray ARPES). Core level photoemission, resonant photoemission and X-ray absorption spectroscopies will be accessible in the whole energy range. The energy selection is obtained by an Hettrick-Underwood monochromator without entrance slit. The optical arrangement, with 3 spherical mirrors (SM) and 4 plane varied line-spaced (VLS) gratings, is able to cover the entire energy range of the beamline. The monochromator includes the motions to select and do the fine adjustments of the mirrors (pitch and height), and to scan the energy and select among the different gratings (grating pitch and grating horizontal translation). The monochromator has been designed by the ALBA team of engineers, and has been fully assembled and commissioned at the facility. Besides the required range and resolution performances, it has been designed to achieve high stability and reproducibility, and optimal performance of the optical surfaces under different heat loads and conditions. The cooling circuits of mirrors and gratings are mechanically decoupled from the optical elements. In the case of the gratings, heat load is removed by flexible copper straps connected from optics to rigid water lines, through temperature controller devices based on Peltier elements. The use of Peltier element allows stabilizing the temperature of the gratings to room temperature also under quickly varying heat loads. The gradients within the grating are well below the one degree, and the thermal equilibrium with the surrounding mechanics contributes the long-term stability of the system. The water circuit and the Peltiers, rest in an independent platform inside the vacuum chamber, that allows them drift freely with no effect on the position of optical elements. In the case of the mirrors, the water tubes and cooling pads are not pressed against the mirrors, but just in contact through a 0.1 mm thick pellicle of eutectic InGa. This allows for a very efficient heat transfer using a minimum contact surface sufficient to evacuate up to 60 W, and without any deformation of the mirrors. The mechanics are also designed so that no flexible loops are required, which contributes to a better vibration stability of the system. Mirrors and gratings can be removed from the monochromator inside their holders and with the cooling scheme installed on it. This is a mandatory goal of design, as it is necessary for a careful installation and control of surface deformations at the optics laboratory. In this contribution we describe the main features of the monochromator that allow reaching the target performances, especially those concerning the cooling scheme. And also, we provide details about the positioning mechanics of the optical elements, the energy scanning

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mechanism and the vacuum system. The monochromator has been already mounted and installed and it is already in operation. The first results of the He photoionization spectra shows an energy resolution better than 10meV at 60eV, with a strong ionization signal and very low noise.

1. General description

LOREA is a 10-1000eV soft X-Ray beamline to study the electronic structure of solids by Angle Resolved Photo-Emission Spectroscopy (ARPES). Core level photoemission, resonant photoemission and X-Ray absorption spectroscopies are accessible in the entire energy range.

The whole design of the monochromator, which includes a novel cooling design of the gratings, has been fully developed at ALBA. The BL20 Monochromator is based on a Hettrick-Underwood geometry with 3 spherical mirrors (SM) and 4 plane varied line-spaced (VLS) gratings to cover the entire energy range of LOREA.

Optics and mechanics work at ultra-high vacuum (UHV) regime. It is considered a big circular vacuum chamber for gratings plus one of the mirrors and two additional chambers for remaining two mirrors. An extra chamber contains part of the gratings pitch mechanism.

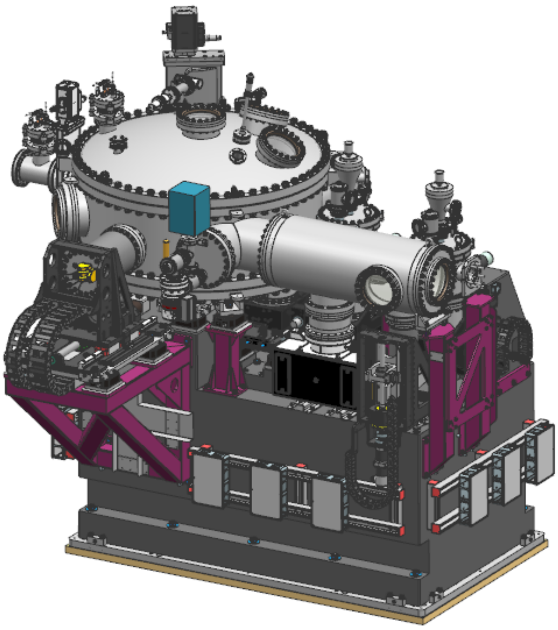


Figure 1. External view of BL20 Monochromator.

2. Gratings mechanism

The gratings mechanics, which can locate up to five gratings, consists on a frame that can be moved transversally to the beam to select the suitable grating. This frame is mounted on an oscillating second frame that produces gratings pitch and it is commanded by a sine arm of 1m long.

The entire mechanism is placed in vacuum, except the actuator of the sine arm. Two welded bellows, one of them connected to the support and thus standing all the force, compensate the vacuum force on the actuator. The vertical actuator, guided by cross roller linear guides consist on a preloaded satellite roller screw with roller recycling spindle that provides high stiffness and small pitch. Between the sine arm that describes an angular trajectory and the actuator that is lineal, there is a connecting rod with two doubled-ended flexural pivot bearings to reduce as much as possible rolling elements.

Regarding transversal motion, an UHV motor, vacuum adapted guides and spindle are installed, mounted directly on the pitch frame. As grating cooling lines are not linked directly to the optics, there is an extra actuator called services motion. This motion is in charge to move cooling fixed water circuit and the main cabling installed. Services motion is placed out of vacuum and has preload ball recirculating spindle and guides. It moves together with UHV grating exchange motion as a pseudo-motor. For the pitch motion, there are two angular absolute encoders to remove the residual eccentricity of mechanics.

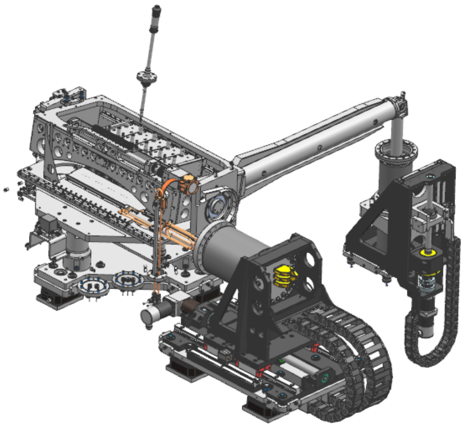


Figure 2. Gratings system design.

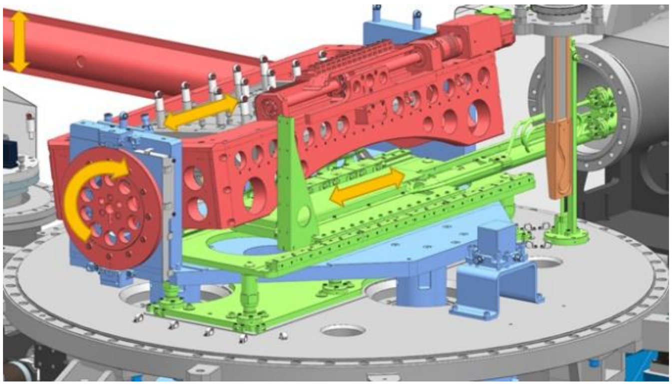


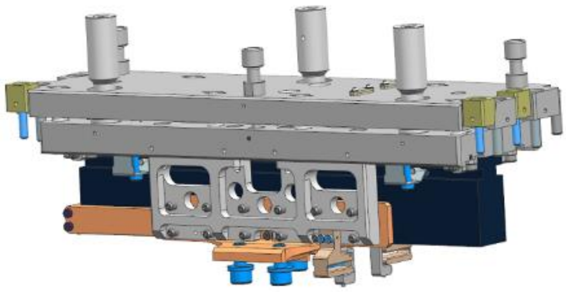
Figure 3. Motions involved at grating system.

Figure 3 shows the different motions that are involved at gratings mechanics. Grating holders are in the middle in grey colour. Red coloured parts are the pitch frame plus sine arm. In green colour, the services motion fully decoupled, and in blue, the parts of pitch frame support.

The system rests on a big natural granite that is the reference for all mechanics (seen at Figure 1).

3. Gratings holder

Each grating is mounted on an independent holder that can be disassembled from mechanics to be adjusted at lab (Figure 4). It consists in two base plates. One is fixed to be connected on the frame. And the second, it is adjustable where the grating is clamped. There are three micrometre screws for the fine adjustment. Pitch and roll angles can be adjusted during operation through vacuum screwdriver. Also fixed to mobile base with the grating, there are three fiducial marks always accessible to have a reference of the mirror. The holder also supports two symmetric OFH cooper cooling pads. These pads, decoupled from the cooling pipes, also hold the protection chin guard.



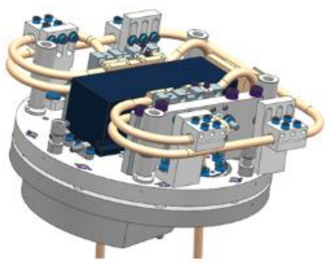


Figure 4. Gratings holder left. Mirrors holder right

4. Gratings cooling

In this design, doubled vacuum piping has been avoided. Cooling line is a single cooper pipe without any intermediate joint fixed at services actuator. Between pads placed at optics and cooling lines, flexible OHF Copper multi foil straps are used.

In order to avoid the rise of equilibrium temperature at optics caused by the distance between the heat source and the cooling pipes, a Peltier module is placed between water pipes and straps [2]. The Peltier module, applying an electrical current produces a ΔT between faces. The objective is to maintain the hot side of Peltier at 23 deg and adjust the temperature of the cold side in order to keep optics at a constant temperature also of 23 deg.

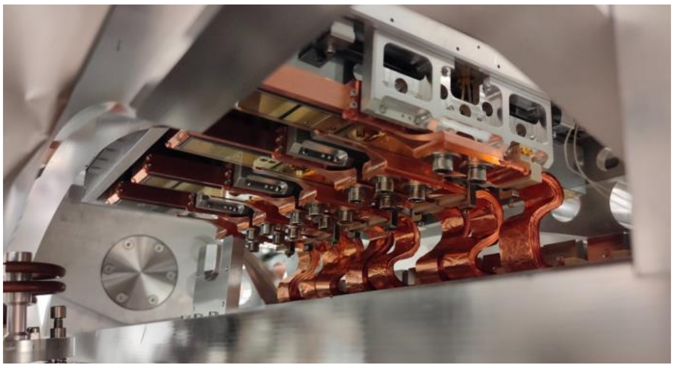


Figure 5. Cooling final design. Straps working “S” shape.

To prove this concept, a protype was produced. It consisted on a silicon substrate including copper pads, straps and Peltier modules with cooling water lines, all in vacuum. A heater simulated the heat load and thermocouples were used as temperature sensors. One of them closed the control loop of Peltier current. Tests have been performed increasing the heat load at the silicon to see the thermal response of the system. The 400 mA corresponds to 4 W, maximum power expected. Figure 6 shows the results.

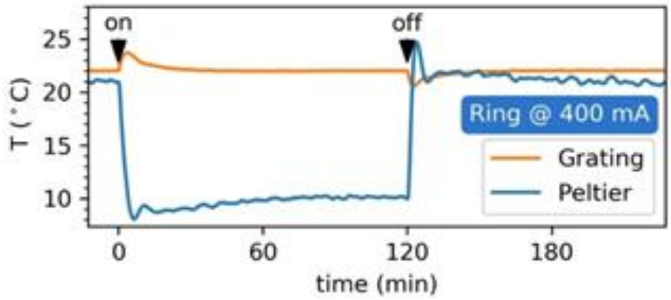


Figure 6. Gratings cooling prototype results.

Orange line corresponds to silicon temperature and blue line, the cold side of the Peltier. At ON point, heater starts to give power increasing temperature. Also, the control starts to put current to the Peltier drooping the temperature of the straps. The dynamic response is quite fast, the stabilization time is around 9 minutes with a ΔT of 1.7 deg. After set point is reached (23 deg), the temperature is maintained very stable via modulating the Peltier current. Once the load is removed, OFF point, the inertia of the system is continuing cooling down the mirror. Then, the polarity of Peltier is inversed acting as a heater to recover temperature. The prototype validated the concept of Peltier modules and flexible cooper straps to allow the relative motion and also decouple from vibrations due to water-cooling flow.

The system can stabilize the temperature of the optic (grating in this case) for a wide range of absorbed power values. The cooling capacity is adjusted rather than complementing the power deposited on the optic by additional resistors [3, 4].

5. Mirrors mechanism

Mirror with holder are placed on a column mounted rigidly to a blank flange connected on a frame with curved linear guides to allow pitch motion. The centre of these guides is pointing at the central axis of the mirror surface. Externally there is an edge welded bellow to allow motion. This scheme was used also on MIRAS at ALBA [1].

The pitch stage is mounted on custom linear stages. Two verticals for SM173 and SM176, to put them at beam height or remove it. And one horizontal, transversal to the beam for SM162, that has two optical stripes. All moving elements, spindles and guides, have preload recirculated balls. Linear stages are mounted on small granites. Every mirror is a stand-alone system and can be aligned independently. After that, the tree mirror systems are placed on the main granite support. SM162 mirror is placed at the same vacuum chamber that gratings and for SM173 and SM176 there are independent vacuum chambers.

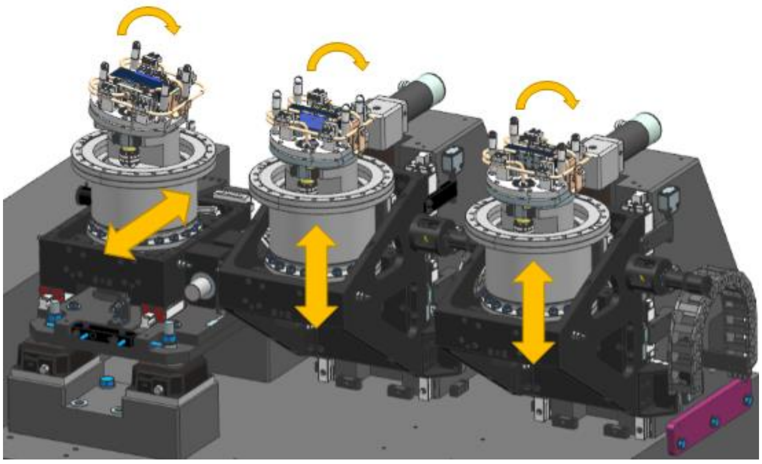


Figure 7. Mirrors motions. SM162, SM173 and SM176.

6. Mirrors holder

As gratings, each mirror is mounted on independent holders that can be disassembled from motion actuators (Figure 4). They consist on two base plates. One is fixed and connected at the main column, and the second, adjustable via three micrometre screws, and is where the mirror is clamped. Also fixed with the mirror, there are the fiducial marks. The holder also supports symmetric cooper cooling pads with fixed cooling circuit. The protection chin guard is also fixed at holder.

7. Mirrors cooling

The cooling water circuit is a continuous rigid cooper pipe that goes inside vacuum and it is fixed at internal mirror mechanics. The flexible lines out of vacuum absorb all the bending motion. The cooling circuit has two brazed cooper pads. There is an adjustable 0.1mm gap that is filled by a Eutectic InGa. Tests have been done to ensure a good behaviour of the InGa, even during bake outs (80 deg).

The solution, with no direct contact between the cooling pads and mirrors, reduces the deformations and stresses that might be introduced to the mirror when clamping. The assembly process is the following, half of the material is applied at the mirror on the surface contact and the other half is applied at copper pads. Notice that cooper pads must be nickel plated because eutectic InGa is very aggressive to cooper. After that, pads and optics must be mounted at final place controlling the gap between them. Once the gap is achieved, the cooling pad is fixed.

8. Mechanics metrology

Table 1. Gratings & mirrors mechanism measured performances.

Parameter	Pitch gratings	Exchange gratings	Pitch (x3) mirrors	Z (x2), X mirrors
Total range	±5.5 degrees	±150 mm	±1 degree	+40 mm/±10 mm
Resolution	0.085 µrad/ 2 half steps	0.155 µm/ half steps	0.232 µrad/ 2 half steps	0.998 µm/ half step
Repeatability	0.77 µrad	17 µrad	1.39 µrad	0.18 µm
1st Resonance mode	56 Hz		74Hz	

Gratings and mirrors systems metrology have been done by Renishaw ML10 interferometer and autocollimator.

9. Beamline measurements

After commissioning of monochromator and rest of systems, beamline is ready to start measurements. ARPES spectra of SeV_2 at 72eV is shown in Figure 8. Thanks to good behaviour of the instrument, total beamline resolution is down to 10meV (beamline plus analyser).

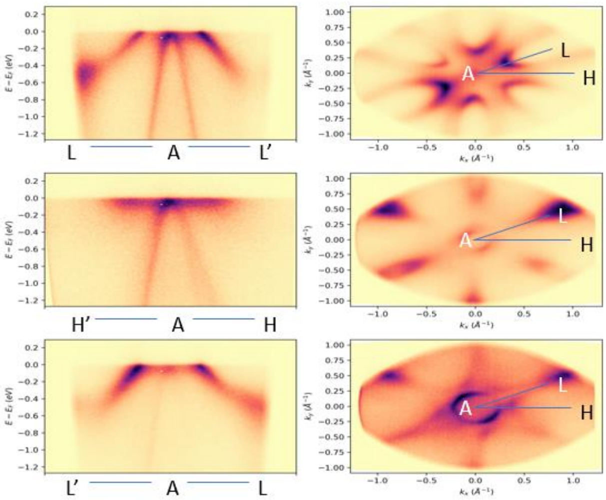


Figure 8. SeV_2 at 72eV ARPES measurement. Left: Band dispersion in various high symmetry directions. Right: Iso-energy surfaces at various binding energy:

Eb=0, Fermi level (top). Eb=-0.5eV (middle).

Eb=-1eV (bottom).Beamline resolution of 10meV.

10. Conclusions

High-performance soft x-ray monochromator has been designed and built at ALBA. Cooling is mechanically decoupled from grating pitch mechanism and Peltier cooling allows high efficiency and active stabilization temperature. Regarding mirror system, it is also a high stability system. Thermal contact between cooling and mirror is enhanced via a wet interface which minimizes mechanical deformations of the mirror. Finally, excellent results are confirmed by metrology and experimental data.

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