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Quarterly Progress Report Q2 FY20 Jan-Mar 2020

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Quarterly Progress Report Q2 FY20 Jan-Mar 2020

Project: Gamma-Ray Mirrors

Project Number: LL19-ML-SNF Content via K-shell X-rays-PD1Lb

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HQ Project Manager: Chris Ramos

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Progress this quarter

During the second quarter of FY20, the optic design, or Phase II Task 2 of the project, continued. Our investigation of two full revolution shell designs has shown that the radius of the optic would be small to maintain throws to reasonable limits. These efforts are informing our alternative segmented optics design in Q3. We have also started investigating the Kirkpatrick-Baez Optic as a backup option.

Optic design

Two full revolution designs have been assessed assuming perfect reflectivity: a single shell Wolter I microscope, a design based on the Z Wolter, and a single shell concentrator made of an ellipsoidal or a conical mirror. Full revolution means that the optic is built as full 360-degree multilayer and shell deposited on a mandrel with the exact Wolter geometry, the optic is then released from the mandrel. A segmented optic is made out of segments that will be shaped in conical approximation of the quadratic surfaces, a hyperbola and an ellipse in the case of a Wolter 1 microscope. For a segmented optic, mirror segments forming a shell need to be coaligned and are separated by small gaps, and segments from successive layers are aligned with separators bonded to the surface. As a consequence, a segmented optic has a smaller effective area than a full revolution optic. However, modeling of the full revolution optic gives us useful insight in the desired geometry for the segmented optic.

Parameters to be considered are the size of the object or source, the mirror radius, the distances between source and detector, source and optic (figure 1.). The range of grazing angles depends on photon energy. Table 1 shows the dimensions when the incident angle on the mirror is 0.111deg, the object-mirror distance > 2m, and the mirror-detector distance >100 mm. To limit the distance between source and detector, the optic radius has to be of order of 0.5 to 2.5 cm. The radius of the Z Wolter considered to be the state of the art is of order 1.7 cm. However, the Z Wolters are designed to image either Mo or Ag X-ray emission lines at 17.48 keV and 22.16 keV respectively. The requirements for the roughness of the mandrel on which the multilayer and then the shells are deposited, and for the multilayer d-spacing at these energies are less stringent than at 100 keV. To our knowledge, they have not been achieved in the full revolution configuration yet. Note that the multilayer and shell deposition systems are very different for a full revolution optic and a segmented optic which we have experience

with. This study highlighted that single shell full revolution optics are beyond state-of-the-art for our application and would not be feasible without significant R&D investments in the fabrication and deposition processes. However, this does not affect the project since fabrication was not the goal. The purpose this study was to inform possible designs based on segmented approximations of some of these geometries.

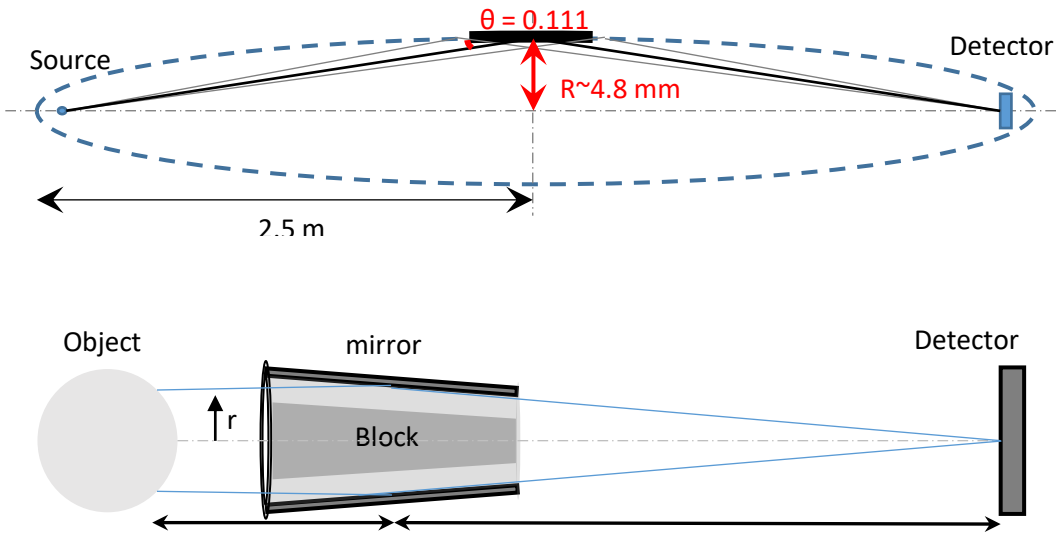


Figure 1. Examples of concentrators: ellipsoidal mirror (top) and conical mirror (bottom)

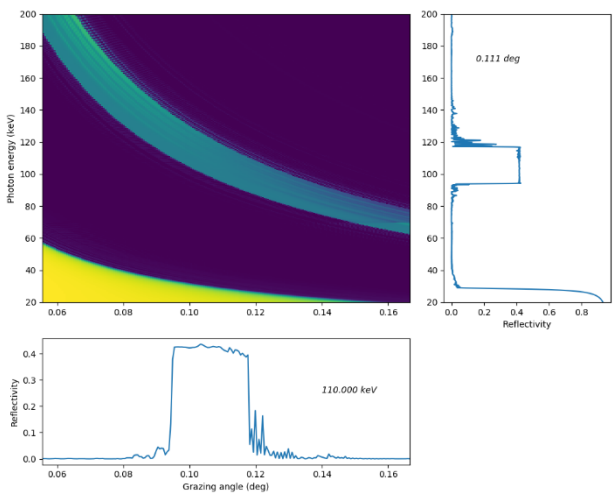
Table 1: Example of dimensions for conical mirror to minimize the source to detector distance. Three constraints were set: incident angle on the mirror 0.111deg, object-mirror distance > 2m, mirror-detector distance >100 mm

Mirror radius	**5 mm**	**10 mm**	**15 mm**	**20 mm**	**25 mm**
Cone ½ angle [deg]	-0.1090	-0.1090	-0.1090	-0.1090	-0.1090
"Object radius"	5 mm	10 mm	15 mm	20 mm	25 mm
Object – mirror distance	2.01 m	2.01 m	2.01 m	2.01 m	2.01 m
Mirror – detector distance	1.30 m	2.60 m	3.91 m	5.21 m	6.51 m
Object – detector distance	3.31 m	4.61 m	5.91 m	7.22 m	8.52 m

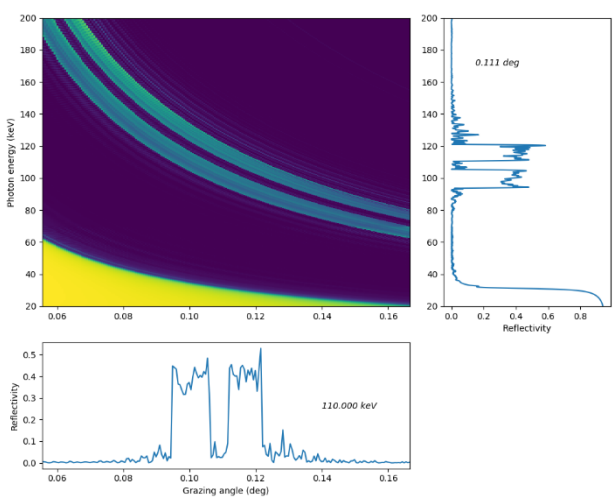
Models are being developed to assess other designs including Kirkpatrick-Baez Optic or KBO, a segment of optics Wolter 1 telescope and of the concentrator. Different configurations of nested flat optics are also being considered. Our expert in KBO has significant experience using crystals in a beamline setting and estimated that mosaic crystals could be worthy candidates. He will be conducting a small evaluation to determine if there are obvious showstoppers to the use of mosaic crystals in the context of the NDA of spent nuclear fuel.

Multilayer coating:

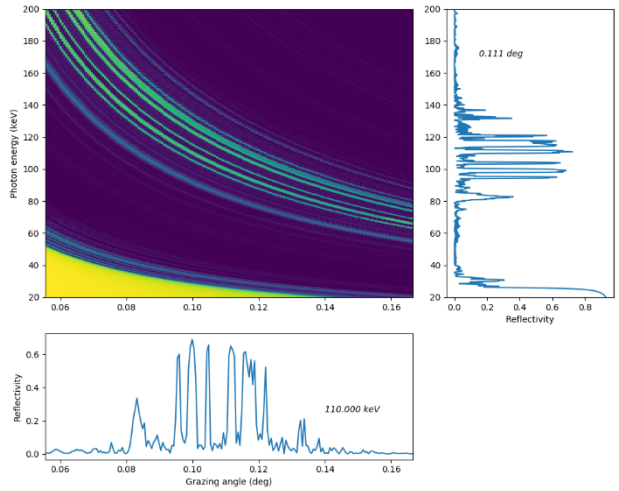
Last quarter our team generated and validated an aperiodic model against existing aperiodic multilayer data at wavelength. This quarter, aperiodic W/SiC and W/SiC multilayers were designed with three different prescriptions aimed at increasing reflectivity: a narrower bandpass from 94 keV to 117 keV, two bandpass range for U and Pu K_α and for U K_β. and a comb-like response matching the U and Pu K lines. Figure 2 shows the modeled reflectivity as a function of energy and angle for the three classes of ML. Narrowing the band pass range from 90-135 keV to 94-120 keV increases the average reflectivity from ~30% to 40% for the single and two bandpass ML. Put in the context of a two-reflection optic, increasing the ML reflectivity from 9 to 16%. The comb-like response of the third ML reaches reflectivity of 60%. Note this is a high-risk concept since the deposition and characterization of such a multilayer have not been tested.



WC/SiC
bandpass 94-117 keV



W/SiC
2 bandpass 94.2-104.2 keV and
109.9-121 KeV



W/SiC 'Comb' response

	Band [keV]	Lines
1	94.2 – 95.2	U Ka2
2	97.9 – 100.1	U Ka1 Pu Ka2
3	103.2 – 104.2	Pu Ka1
4	109.9 – 111.8	U Kb3 U Kb1
5	114.0 – 117.8	U Kb2 Pu Kb3 Pu Kb1
6	120.1 – 121.1	Pu Kb2

Figure 2. Aperiodic W/SiC and WC/SiC multilayer response R(E,θ) with lineouts at E=110 keV (horizontal) and θ=0.111deg (vertical).

Outlook

The plan is to continue the design study in Q3 of FY20.

Publications

- Preparation of presentation for NSARD2020 review

Lab Program Manager Comments [optional]:

Opportunity for lab PM commentary if needed.

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