SCD CRLs

Single Crystal Diamond Compound Refractive Lenses

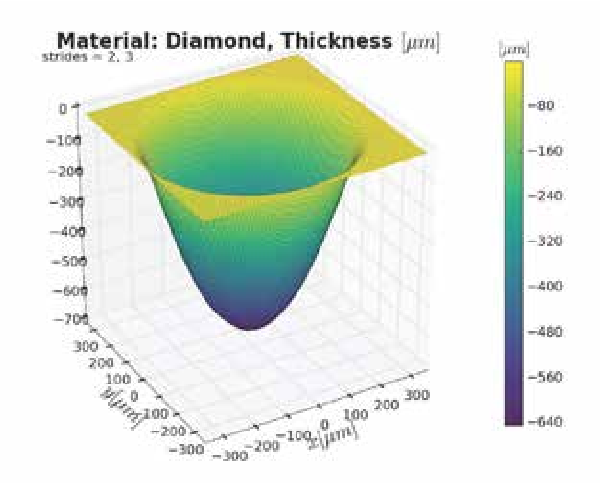
JJ X-RAY

Danish Science Design

REFRACTIVE OPTICS

The use of refractive optics in the synchrotron community has become steadily more widespread since the beginnings in the early 1990ties and is today among the standard options for collimating or focusing hard X-Rays.

JJ X-Ray has been working with refractive lenses both scientifically and commercially, since 2002 and share the enthusiasm of their outstanding performance regarding both ease of use, alignment and their close to perfect focusing.



Lens shape measured at 1-BM, APS.

WHY CHOOSE SDC CRLs?

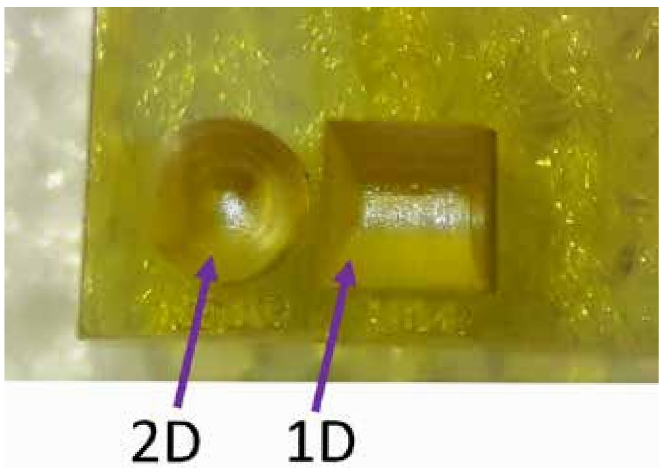
We both offer single crystal diamond lenses (SCD CRL´s) and conventional lenses shaped in beryllium, aluminum and nickel as the energy increases.

Metal based CRL are intrinsically limited by the grainy structure within the lens material – a drawback that is enhanced in applications that require a coherent beam, strong focusing or defocusing of the beam.

Single crystal diamond is an excellent alternative material for CRL´s as it can be virtually free of inclusions, voids and grain boundaries. Further, diamond has a low x-ray absorption, a high radiation hardness and an outstanding heat conduction also making it an ideal material for white x-ray beam applications. To maximize possible heat conduction away from the diamond, the packaging material offered by JJ X-Ray is a Cu disk into which the diamond is permanently press fitted.

SHAPING A DIAMOND

The lens shape is carved using a short-pulsed laser and subsequently the surface roughness is improved by various wet and dry etches. The dry etches are also be used to minimize the web between the bi-concave diamond lenses. The shape of the lens can be made relatively freely and thus be tailored to the parameters of the specific beamline, they will be deployed for. It is also possible to make multiple lenses in one diamond. This means that for instance a single translocator can accommodate both a 2D CRL and a 1D focusing CRL using the same lens cassettes.

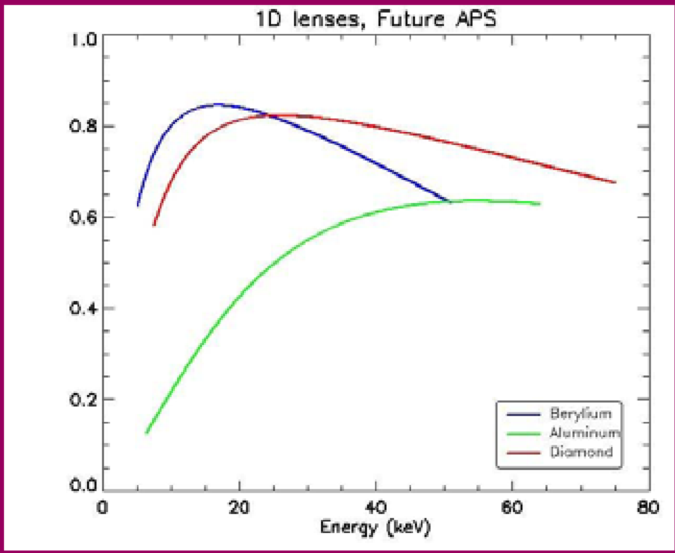


2D CRL and 1D CRL using the same lens cassette.

SCD CRL FEATURES

The relatively high refractive index of diamond paired with a low absorption cross section means that they can be used as optical components over a wide energy range, 5 – 90 keV.

In the figure, the available flux from Br, Al and Diamond lenses are shown as a function of energy. As seen, diamonds offer the highest flux from the mid-twenties to the eighties (and note here that the calculations are made with a conservative web distance – a parameter we are continually improving).



CRL Normed flux availability for a 1D lens made in Be vs Al vs Diamond when focusing with p=46.7m, q=56.5m and a lens number N between 1-95. By courtesy of Mati Meron APS, 2018.

BEAM STABILITY

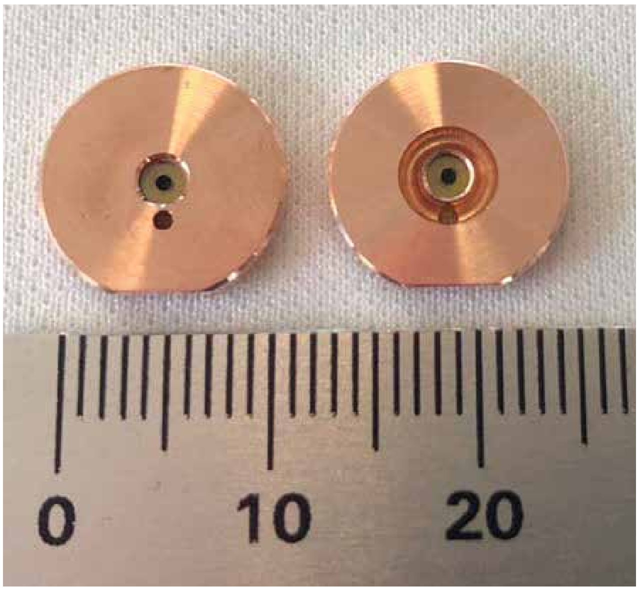
A key feature of CRL focusing is that it is significantly less sensitive to vibrations than for instance mirror focusing: The moment transfer of a reflective mirror and a refractive CRL is given as below, where k is the is the wave vector, ϑ is the incidence angle (or angular vibration), N is the number of lenses (typically between 10 and 100 lenses are used) and δ is the real part of refractive index (which is a material and energy dependent number, but is typically in the order of 10^{-6}):

Mirror $Q = 2k \sin \vartheta$

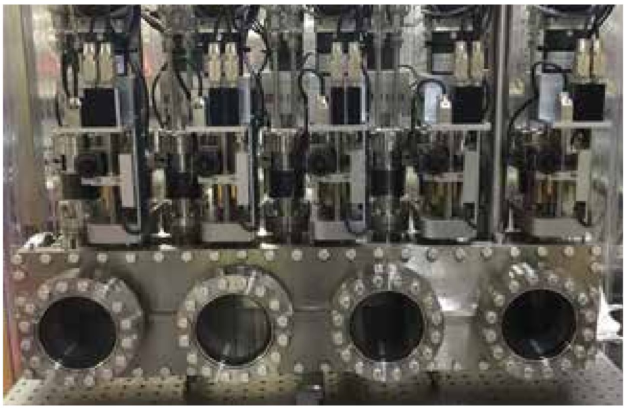
CRL $Q = N^{½} k \delta$

By this, it can be deduced that lenses are in the order of at least for all practical purposes, 100 times less sensitive to vibrations. The same principle can be applied to surface contaminations, so CRL´s are basically insensitive to for instance carbon depositions.

See J. Synchrotron Rad. (1999) 6, 1153-1167 for further details.



Cu disks fitted with SCD CRL´s.



Water cooled CRL System.

BACKGROUND FOR SCD CRLs

JJ X-Ray and the Danish Technical University have over the last two years been developing Compound Refractive Lenses (CRL) of Single Crystal Diamonds (SCD´s) and will continue the development in foreseeable future. Currently, what we call the generation II lenses, GII, are available for purchase. GII lenses have a height error below 3 µm RMS as confirmed by 1BM measurements at the APS in Chicago, see figure 1. In figure 2 the focusing capability of the GII lenses are shown where a 8 keV beam is focused down to 2.1 times the theoretical possible.

GIII lenses will be evaluated at the APS in December 2019 and are set to be available in spring of 2020. The long-term strategy is to release a new generation every 18 months. Discounts will be given to customers wishing to upgrade their SCD lenses to later a generation.

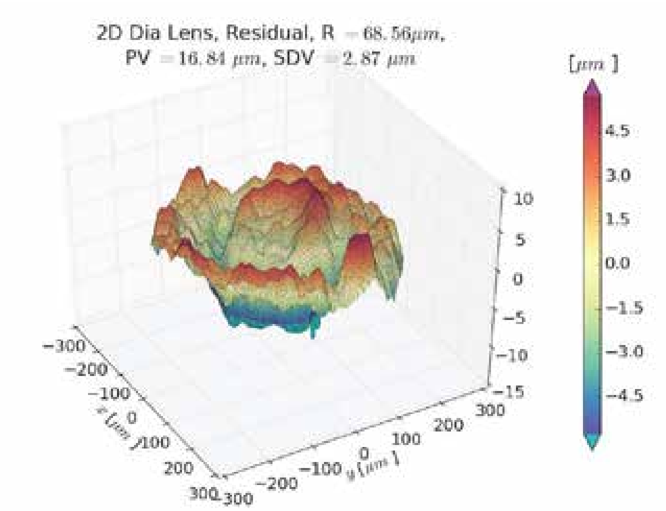


Figure 1: Residual height error of a SCD lens. The doughnut like height error is systematic for the GII lenses.

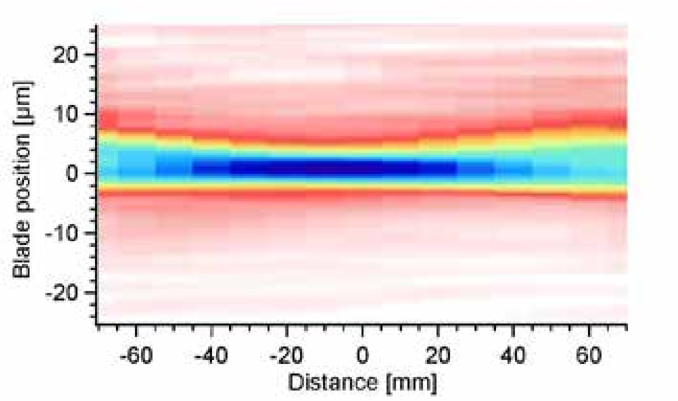


Figure 2: Focusing capability of the GII lenses.

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Synchrotron Beamlines