Fast Adaptive Resonant X-Ray Optics

J Evers[1]

[1] *Max Planck Institute for Nuclear Physics, Heidelberg, Germany*
Contact Email: joerg.evers@mpi-hd.mpg.de

Visible light can easily be manipulated using reflective or refractive elements, such as lenses, phase plates, or mirrors. At hard X-ray energies, these concepts require a revision since the real part of the complex refractive index of any material approaches 1. As a result, an impressive toolbox of alternative methods has been developed, most importantly based on crystal optics. By now, also adaptive and active X-ray optics are mature fields. However, many of the established techniques operate on timescales which are not compatible with that of typical experiments involving narrow X-ray resonances, such as those provided by Mössbauer nuclei.

Here, I will discuss a new concept for fast adaptive X-ray optics, which in particular aims at the dynamical control during single cycles of an experiment [1]. Our approach builds upon piezo-control methods, which are well-established in the Mössbauer community, and which allow one to mechanically displace a solid-state target containing resonances much faster than the lifetime of the resonances. Such displacements give rise to relative phase shifts, and we have previously employed those shifts to shape the spectra of X-ray pulses [2] and to coherently control the dynamics of Mössbauer nuclei [3].

For applications in X-ray optics, we associate the phase shifts to an effective real part of the refractive index of the resonant material. Since the amount of mechanically induced phase shift imposed on the X-ray light is independent of the thickness of the target, we find that the real part of the X-ray refractive index can effectively be increased substantially without an increase of the absorptive imaginary part. Our approach thus provides access to enhanced refractive index contrasts at X-ray energies together with low absorption. Unlike in conventional refractive optics, this phase manipulation only occurs over the narrow spectral range of the involved resonance. This, however, is not a limitation if the light is used to interact with resonances of the same type afterwards, as it is common in Mössbauer science.

After introducing our method, I will discuss several applications based on the dynamical manipulation of the polarization state of X-ray pulses *via* a mechanically-induced birefringe and show results of a proof-of-principle experiment.

References

[1] M Gerharz, J Evers *et al.*, in preparation

[2] K P Heeg, A Kaldun, C Strohm, P Reiser, C Ott, R Subramanian, D Lentrodt, J Haber, H-C Wille, S Goerttler, R Rüffer, C H Keitel, R Röhlsberger, T Pfeifer and J Evers, Science **357**, 375 (2017)

[3] K P Heeg, A Kaldun, C Strohm, C Ott, R Subramanian, D Lentrodt, J Haber, H-C Wille, S Goerttler, R Rüffer, C H. Keitel, R Röhlsberger, T Pfeifer and J Evers, Nature **590**, 401 (2021)