Berry-Phase Translation Effect in Strain-Engineered Hydrogenated Dilute Nitrides: A Novel Approach to X-ray Photonics

M. Felici[1], G. Pettinari[2], M. Fratini[3], L. Barba[4], G. Campi[5], S. Rubini[6], and A. Polimeni[1]

[1]*Physics Department, Sapienza University of Rome, 00185 Rome, Italy*
[2]*Institute for Photonics and Nanotechnologies (IFN), National Research Council (CNR), 00156 Rome, Italy*
[3]*Institute of Nanotechnology (Nanotec), CNR, c/o Phys. Dept., Sapienza University of Rome, 00185 Rome, Italy*
[4]*Institute of Crystallography (IOC), CNR, 34149 Basovizza (Trieste), Italy*
[5]*Institute of Crystallography (IOC), CNR, 00015 Monterotondo (Rome), Italy*
[6]*Istituto Officina dei Materiali (IOM), CNR, 34149 Basovizza (Trieste), Italy*

marco.felici@uniroma1.it

As theoretically predicted in [1] and experimentally demonstrated in [2], X-rays travelling through a deformed periodic medium undergo unexpectedly large beam translations (>100 μm), due to the presence of Berry curvatures [3] in both real and reciprocal space. These curvatures, associated with the parametric dependence of the propagating electromagnetic wave packet on its position and wavevector, are respectively due to the crystal deformation and to the lattice periodicity, which introduces a band structure (*i.e.*, it opens a band gap) in the photon dispersion relation. More precisely, it is the coupling between real- and reciprocal-space curvatures that leads to the acquisition of a non-negligible Berry phase by the X-ray wave packet. This extra phase strongly affects X-ray propagation, eventually giving rise to the observed beam translations. In this work (see Fig. 1) [4], the strain modulation required to induce the Berry-phase effect was obtained by pairing the lattice expansion observed upon H irradiation of GaAsN [5] with the spatially selective hydrogenation technique described in, *e.g.*, [6]. By performing a series of X-ray transmission experiments on purposely fabricated, ordered GaAsN/GaAsN:H dot arrays, we consistently measured beam translations in excess of 100 μm, while also revealing a clear dependence of the observed translation on the dot size. These experimental results were compared with an extensive numerical analysis of the propagation of X-rays in the deformed lattice, based on the direct computation (via FEM calculations) of the deformation landscape within the sample [4]. These results open new, enticing prospects for the realization of tailor-made X-ray photonic structures, interesting for applications in pump-and-probe experiments and in X-ray interferometry.

References

[1] K. Sawada *et al.*, Phys. Rev. Lett. **96**, 154802 (2006).
[2] Y. Kohmura *et al.*, Phys. Rev. Lett. **110**, 057402 (2013).
[3] M. V. Berry, Proc. R. Soc. Lond. A **392**, 45 (1984).
[4] M. Felici *et al.*, *in preparation*.
[5] F. Berenguer *et al.*, Commun. Mater. **1**, 19 (2020).
[6] M. Felici *et al.*, Phys. Rev. B **101**, 205403 (2020).

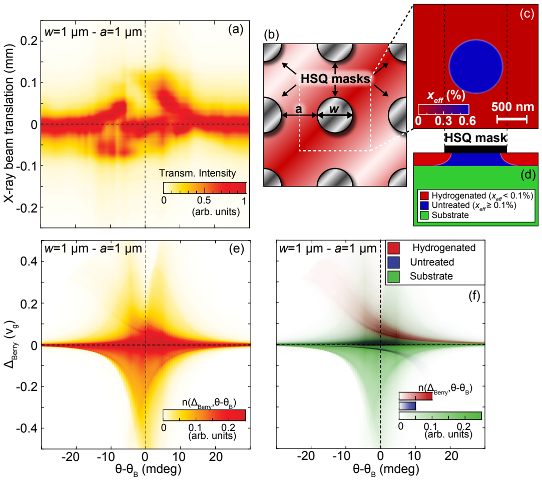

Fig. 1. (a) Measured X-ray translation in a GaAsN:H/GaAs dot array. Both the diameter (*w*) and the edge-to-edge spacing (*a*) of the mask employed to create the array control H diffusion were set to 1 μm in the displayed sample. The X-ray translation is monitored as the sample is rotated around θ_B, the Bragg angle corresponding to the (004) direction of GaAs. (b) Schematic view of the mask deposited on the sample prior to H irradiation (*w* = 0.2, 0.5, and 1 μm in this work). (c) Spatial distribution of the unpassivated N concentration (x_{eff}) in the epilayer's plane (100 nm above the substrate), as obtained via FEM calculations. (d) Sketch of the hydrogenated sample in the plane cutting across the mask. The substrate is displayed in green, whereas the hydrogenated and H-free regions are shown in red and blue, respectively. (e) Histogram of the computed distribution of Δ_{Berry}, the point-by-point deviation (in the growth direction) of the speed of propagation for X rays travelling through the sample (in units of v_g, the group velocity of the X rays in the material). Δ_{Berry} is also displayed as a function of the rotation of the sample around θ_B, for ease of comparison with the measured X-ray translation. (f) Same as (e), only in this case the contributions of the three sample regions identified in (d) are displayed in different false color scales, consistent with the colors used in (d)