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Pushing periodic disorder induced phase-matching into deep-ultraviolet spectral region

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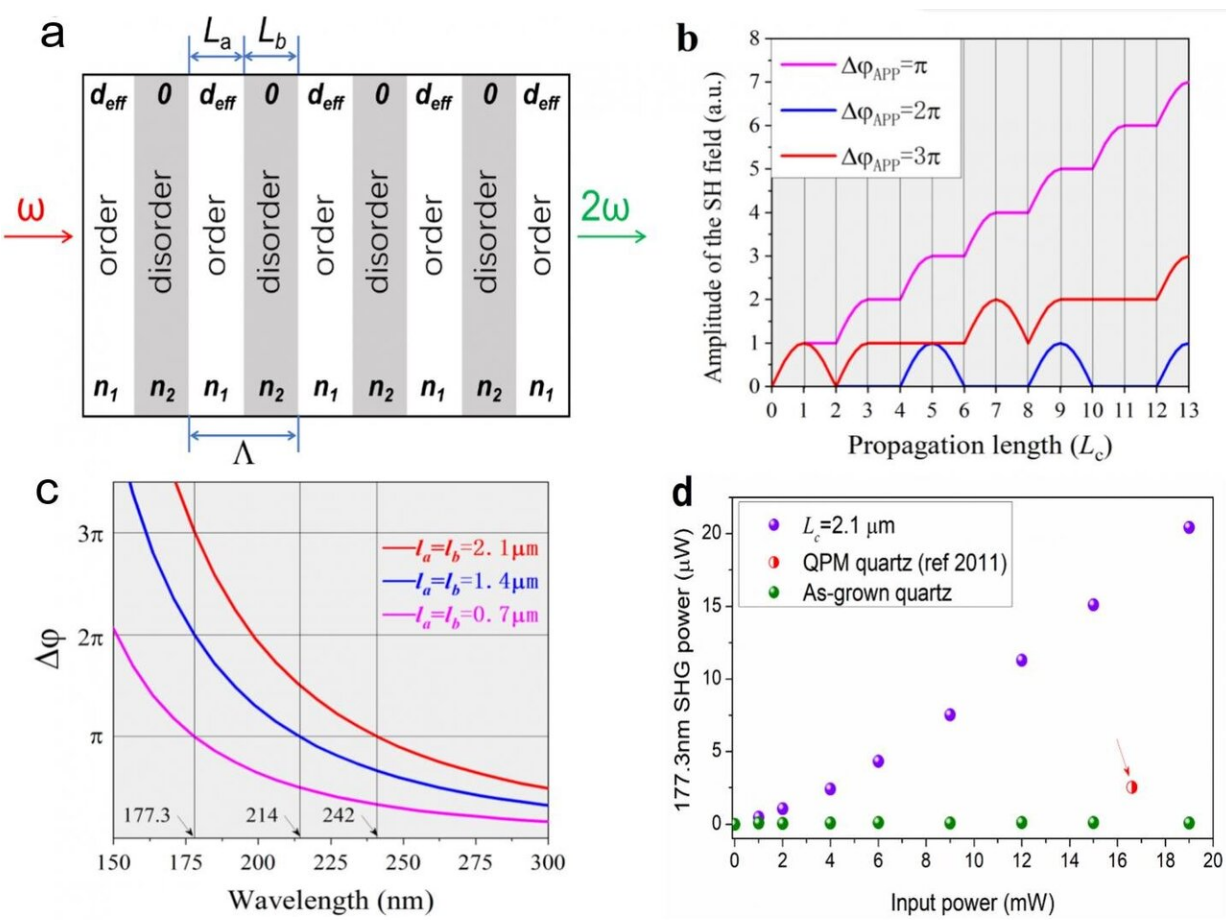

(a) Schematic graph of additional-phase-matching condition in arbitrary nonlinear optical crystals. The white and grey regions represent ordered crystal and disordered amorphous, respectively. The period length Λ equals the sum of ordered width La and disordered width Lb (Λ = La + Lb). Notably, La and Lb may be equivalent to coherent length Lc or integral multiple of Lc. deff/0 and n1/n2 represent the second-order nonlinear coefficient and refractive index of ordered and disordered regions, respectively. (b) Schematic estimation of the SH field amplitude of the APP quartz with different shifted phase ($\Delta\varphi$APP) under the same crystal length. (c) Theoretical calculation of the APP ($\Delta\varphi$APP) with the APP quartz samples of La=Lb= 2.1 μm, 1.4 μm, and 0.7 μm (d) 177.3 nm SHG output power in APP quartz (purple point) with La=Lb= 2.1 μm and $\Delta\varphi=3\pi$ and in as-grown quartz (green point). Credit: Mingchuan Shao, Fei Liang, Haohai Yu, Huaijin Zhang

Phase matching condition is the key criteria for efficient nonlinear frequency conversion. Here, Scientists in China employed an additional periodic phase (APP) technique to meet the phase-matching condition in quartz crystal and experimentally demonstrated the efficient nonlinear frequency conversion from the visible to the deep-ultraviolet spectral region. The APP theory and generated visible to deep-ultraviolet radiation would revolutionize next-generation nonlinear photonics and their further applications.

Nonlinear optical frequency conversion is an important technique to extend the wavelength of lasers which has been widely used in modern technology. The efficiency of frequency conversion depends on the phase relationship among the interacting light waves. High conversion efficiency requires the satisfactory phase matching. However, due to the dispersion property of nonlinear optical crystals, phase mismatching always occurs; thus, phase matching conditions should be specially designed. There are two widely used techniques for phase-matching: birefringence phase matching (BPM) and quasi-phase matching (QPM). Normally, BPM employs the natural birefringence properties of nonlinear optical crystals, and QPM is mainly focused on the periodic inversion of ferroelectric domains. However, most of nonlinear optical crystals hold neither sufficient birefringence nor controllable ferroelectric domains. Therefore, it is urgent to develop new routes to meet phase-matching in arbitrary nonlinear crystals and in broad wavelength ranges.

In a new paper published in *Light Science & Applications*, scientists from the State Key Laboratory of Crystal Materials and Institute of Crystal Materials, Shandong University, China, proposed a concept based on the basic principles of nonlinear frequency transformation, additional periodic phase (APP) from the disorder alignment, which can intercept the energy transmission channel of nonlinear light to fundamental light and compensate for mismatched phases. The APP concept means that after the light propagating at the coherence length Lc, the generated phase difference $\Delta\varphi\_PD$ was compensated by the additional phase difference $\Delta\varphi\_APP$ with $\Delta\varphi\_APP+\Delta\varphi\_PD=2m\pi$ (m is the integer). Based on the APP concept, a periodic ordered/disordered structure is introduced into crystal quartz by femtosecond laser writing technology to achieve an effective output from ultraviolet to deep-ultraviolet at the wavelength of 177.3 nm. More interestingly, the APP phase matching may get rid of the limitations of birefringent and ferroelectric materials on nonlinear frequency conversion and should be applicable to all non-centrosymmetric nonlinear crystals for achieving effective output at any wavelength in the transmission range of the materials.

"To the best of our knowledge, the phase-matched deep-ultraviolet 177.3 nm generation was first achieved via quartz crystal with a high efficiency of 1.07‰," they added.

"This APP strategy may provide a versatile route for arbitrary nonlinear crystals in broadband wavelength. More importantly, this order/disorder alignment adds a variable physical parameter into optical systems, thus leading to next-generation revolution in nonlinear or linear modulation and classical or quantum photonics," the scientists forecast.

More information: Mingchuan Shao et al, Pushing periodic-disorder-induced phase matching into the deep-ultraviolet spectral region: theory

and demonstration, *Light: Science & Applications* (2020). DOI: 10.1038/s41377-020-0281-4

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