Natural three-dimensional nonlinear photonic crystal

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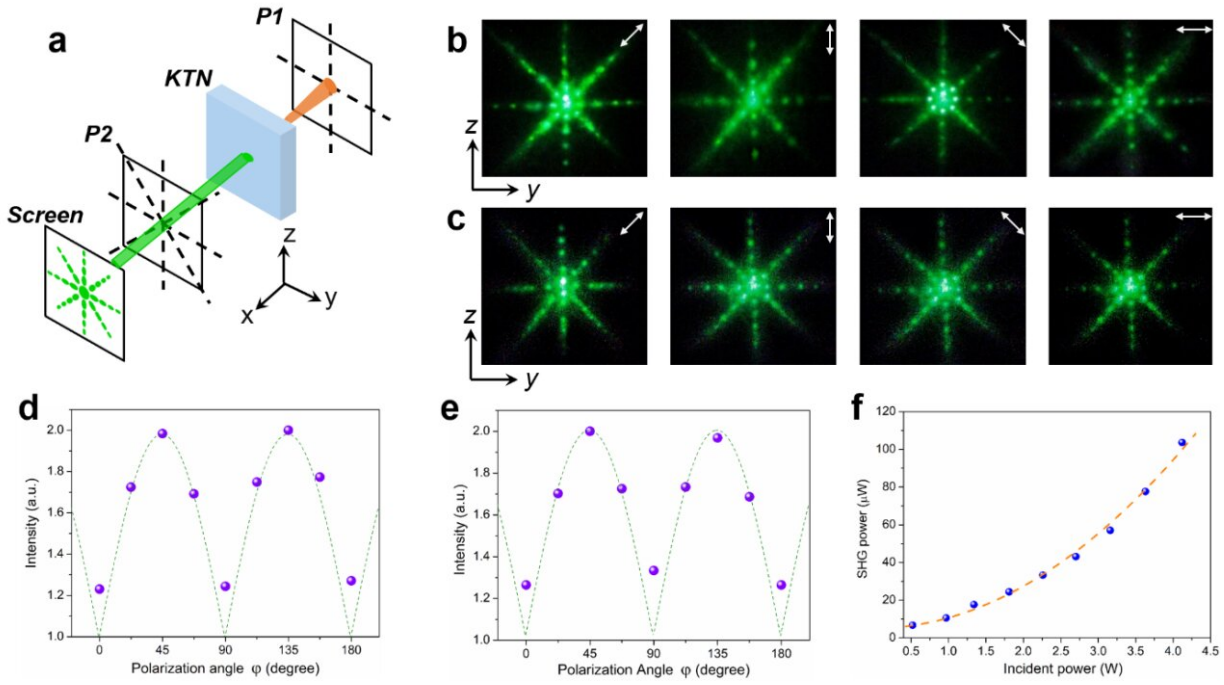

a, Experimental setup for 3D quasi-phase-matching SHG experiment. b-c, SHG spot in different polarization states when the polarization direction of incident fundamental light is along y-axis (b) and z-axis (c). d-e, Relative intensity of SHG in different polarization states when the polarization direction of incident fundamental light is along y-axis (d) and z-axis (e). f, The relationship between fundamental power and SH power. Credit: Chang Li, Xuping Wang, Yang Wu, Fei Liang, Feifei Wang, Xiangyong Zhao, Haohai Yu, Huaijin Zhang

Nonlinear photonic crystals (NPCs) are transparent materials that have a spatially uniform linear susceptibility, yet a periodically modulated quadratic nonlinear susceptibility. These engineered materials are used extensively for studying nonlinear wave dynamics and in many scientific and industrial applications. Over the past two decades, there has been a continuous effort to find a technique that will enable the construction of three-dimensional (3-D) NPCs. Such capability will enable many new schemes of manipulation and control of nonlinear optical interactions.

Till now, only two artificial 3-D NPCs have been constructed using femtosecond laser poling in ferroelectric $LiNbO_3$ and $Ba_{0.77}Ca_{0.23}TiO_3$ crystal. However, both nonlinear crystals only feature up-down ferroelectric domains and no spatially rotating polarization. Therefore, the crystal cutting angle and incident light polarization are still limited to utilize the maximum nonlinear coefficient. The 3-D spatial rotation of ferroelectric domains may break the rigid requirement on incident light in common nonlinear photonic crystals, but seems difficult to reach by traditional electric or light poling technique.

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, and co-workers showed a natural potassium-tantalate-niobate ($KTa_{0.56}Nb_{0.44}O_3$, KTN) perovskite nonlinear photonic crystal with 3-D spontaneous Rubik's domain structures. It exhibits the near-room-temperature Curie temperature at 40° C. The Rubik's domain structure is composed of 90° and 180° domains with different polarization direction. Hence, the ferroelectric domain structures arranged in KTN crystal would supply rich 3-D reciprocal vectors to compensate phase-mismatch along arbitrary direction. Based on this 3-D KTN nonlinear photonic crystal, a second harmonic generation with four-fold pattern spot was demonstrated, which is proved to be the superposition of two orthogonal polarization states in different nonlinear diffraction modes.

"KTN crystal contains 3-D ferroelectric polarization distributions corresponding to the reconfigured second-order susceptibilities, which can provide rich reciprocal vectors for compensating phase mismatch along an arbitrary direction and polarization of incident light," they added.

"KTN crystal is easily compatible to laser writing techniques, thus suggesting promising opportunities to create hierarchical nonlinear optical modulation. Therefore, this 3-D nonlinear photonic crystal in perovskite ferroelectrics would find a wide variety of applications in optical communications, quantum entanglement sources, nonlinear imaging, and on-chip signal processing," the scientists predict.

More information: Chang Li et al, Three-dimensional nonlinear photonic crystal in naturally grown potassium–tantalate–niobate perovskite ferroelectrics, *Light: Science & Applications* (2020). DOI: 10.1038/s41377-020-00427-z

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