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Dynamic tailoring of an optical skyrmion lattice in surface plasmon polaritons: comment

TIM MEILER,* BETTINA FRANK, AND HARALD GIESSEN

4th Physics Institute, University of Stuttgart, Pfaffenwaldring 57, Stuttgart 70569, Germany
*t.meiler@pi4.uni-stuttgart.de

Abstract: We comment on a recent paper entitled "Dynamic tailoring of an optical skyrmion lattice in surface plasmon polaritons" [Opt. Express **28**, 10322 (2020)] and disprove the assertion that Bloch-type skyrmions exist in the magnetic field of surface plasmon polaritons.

Skyrmions are topological quasiparticles in vector fields, such as the magnetic field **B**, which can be classified by the skyrmion number S [1]:

$$S := \frac{1}{4\pi} \oiint_A s dA = \frac{1}{4\pi} \oiint_A \left(\frac{\partial \mathbf{B}}{\partial x} \times \frac{\partial \mathbf{B}}{\partial y} \right) \cdot \mathbf{B} dxdy \quad (1)$$

A skyrmion exists when the integral of the skyrmion number density s over the unit cell A of a periodic lattice is one. Chunyan Bai and collaborators [2] recently reported on novel, optical skyrmions in electromagnetic light fields of surface plasmon polaritons (SPPs). They performed numerical FDTD simulations that retrieved the electric and magnetic field vectors, which form Néel- and Bloch-type skyrmions, respectively. The Néel-type skyrmions in the electric field have already been confirmed [3–5], but the magnetic field forms a flat vortex as depicted by the red arrows in Fig. 1. We explain why this texture is not a Bloch-type skyrmion.

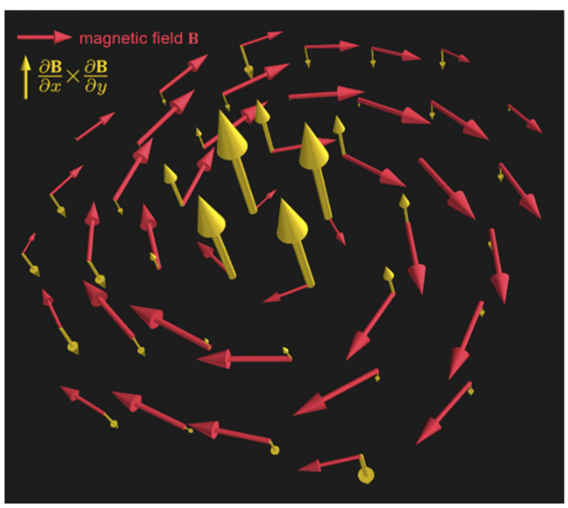

Fig. 1. The magnetic field **B** (red arrows) of the optical skyrmion forms a flat vortex without out-of-plane components. The derivatives in x- and y-direction of the magnetic field vector $\partial_x \mathbf{B}$, $\partial_y \mathbf{B}$ thus also lie in-plane. Their cross product denoted by the yellow arrows is then perpendicular to the magnetic field. The skyrmion number density in Eq. (1) hence vanishes at any point since the dot product of the orthogonal magnetic field and the former cross product is zero. This vortex therefore has a skyrmion number of zero and is not a skyrmion.

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SPPs solely exist for transverse magnetic (TM) polarization [6]. They propagate at the interface between a metal and a dielectric to which they are confined, i.e., evanescently decaying in the perpendicular direction. This system is described by the Helmholtz equations which allow two sets of self-consistent solutions, namely transverse magnetic and transverse electric (TE) modes. The TE mode amplitude vanishes due to the continuity condition of magnetic and electric field at the interface. This means that no surface modes exist for TE polarization. A SPP is defined as a longitudinal excitation which requires an electric field component in the same direction as the wave vector, but the TE mode lacks such a component in the electric field.

Consider a SPP wave in the x-y plane propagating in the x direction then TM modes only possess nonzero electric x- and z-field components as well as a nonzero magnetic y-field component. Thus, the magnetic field has no z-component perpendicular to the interface: $\mathbf{B} = (B_x,\ B_y,\ 0)^T$. We calculate the magnetic field for a hexagonal grating and visualize the flat vortex in Fig. 1 by red vector arrows. The derivatives of the magnetic field in x- and y-direction lie in-plane as well: $\partial_x \boldsymbol{B} = (\partial_x B_x,\ \partial_x B_y,\ 0)^T$ and $\partial_y \boldsymbol{B} = (\partial_y B_x,\ \partial_y B_y,\ 0)^T$. Their cross-product $\partial_x \boldsymbol{B} \times \partial_y \boldsymbol{B} = (0,\ 0,\ \partial_x B_x \partial_y B_y - \partial_x B_y \partial_y B_x)^T$ is illustrated by the yellow arrows in Fig. 1, which are oriented perpendicular to the transverse magnetic field (red arrows). The dot product in Eq. (1) gives the skyrmion number density s that vanishes at every point. The integral over a hexagonal unit cell is the skyrmion number which also results in zero. *Thus, the magnetic field texture forms a vortex but not a Bloch-type skyrmion as it lacks the axial component.* We furthermore extend this statement that none of the skyrmion types exists for in-plane fields.

To prove the existence of skyrmion textures, calculation of the skyrmion number and skyrmion number density in Eq. (1) is indispensable. While optical Néel-type skyrmions have already been experimentally verified [3,5], the Bloch-type skyrmion known from magnetic materials [7] has yet to be found in the novel domain of optical skyrmions.

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Disclosures

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