## **Optical Components using Gauge-Field Metamaterials**

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Gauge fields and associated effective magnetic fields in the real space provide an alternative way in manipulating light. While the sizes and shapes of the local dispersion surfaces are conventionally varied in a gradient material profile, the gauge field approach manipulates light by shifting the centers of the local dispersion surfaces from place to place. The existence of such a gauge field has been proved by recent experiments and such a concept has been applied to achieve novel wave phenomena, such as negative refraction and one-way waveguide using dynamic modulation (Q. Lin and S. Fan, *Phys. Rev. X* **4**, 2014, pp. 031031). Based on these recent developments, we investigate the materialization of such a gauge field using a specific type of anisotropic metamaterials. By using such metamaterials, we further design different optical components enabled by these gauge field profiles, such as beam splitters and asymmetric light propagation through a ring resonator with gauge fields.

In this work, we are interested in metamaterials with permittivity and permeability tensors:

$$\varepsilon = \begin{pmatrix} n & 0 & A_{y} \\ 0 & n & -A_{x} \\ A_{y} & -A_{x} & n \end{pmatrix}, \qquad \mu = \begin{pmatrix} n & 0 & -A_{y} \\ 0 & n & A_{x} \\ -A_{y} & A_{x} & n \end{pmatrix}, \tag{1}$$

while a two-dimensional gauge field in *x*-*y* plane is identified as  $\mathbf{A} = A \hat{x} + A \hat{y}.$ 

$$A = A_x \hat{x} + A_y \hat{y} \,. \tag{2}$$

The local dispersion surface of such an anisotropic medium is split by the gauge field A with pseudo spin-up/down  $E_z \pm H_z$ , as shown in Fig. 1(a), e.g. with parameters n=1,  $A_x = 0$ , and  $A_y = 0.1$ . The degree of this splitting is then varied as a gauge field profile, which enables us to design optical components in a very different way. As an example, we can construct a gauge field profile to give a homogeneous pseudo magnetic field  $B_z \hat{z} = \nabla \times A$ . Then an incident beam with  $E_z$ -polarization, which consists both spin-up and down, splits in different directions, as a gauge-field beam splitter (with simulation shown in Fig. 1(b)). As a further application, we will also show that this specific anisotropic metamaterial can be utilized to demonstrate asymmetric light propagation in a ring resonator with constant gauge field.



Fig. 1 (a) Dispersion surface of the anisotropic metamaterial with parameters n = 1,  $A_x = 0$ , and  $A_y = 0.1$ . (b)  $E_z$  field pattern when a  $E_z$  beam incidents into the splitter (ring region) designed by the gauge field A.