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Affine Nonmagnetic Transformation Design and its Application

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Abstract: Based on the transformation optical design which possesses simultaneously unitary permeability and piece-wise homogeneity, transformation-optics devices can practically avoid magnetism and inhomogeneous parameters, and be implemented directly using existing dielectric materials with ideal performance.

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Transformation optics is applicable to invisibility cloaking [1, 2] and a broad variety of electromagnetic wave converters [3-5], and is moving from theoretical study to practical use. However, the original implementation of transformation-optics device necessitates the utilization of media that are both inhomogeneous and anisotropic. To address this challenge, homogeneous transformation methods [6, 7] were recently proposed and experimentally demonstrated [8-10]. A second limitation to date has still remained: The transformation typically results in non-unit values for the magnetic permeability μ , which, except being renormalization with scattering trade-off [11], is not known generally how to implement in optical wavelengths with conventional optical materials.

To tackle this problem, we introduce a transformation optical design which possesses simultaneously a unitary permeability (*i.e.* nonmagnetism) and homogeneous permittivity. Our design, admitting both macroscale and nanoscale fabrication, can be achieved using natural birefringence materials such as Calcite [8, 9], or via subwavelength anisotropic patterning [12, 13]. Moreover, our geometrical approach simplifies the problem to one of graphical design that in many cases can be carried out analytically.

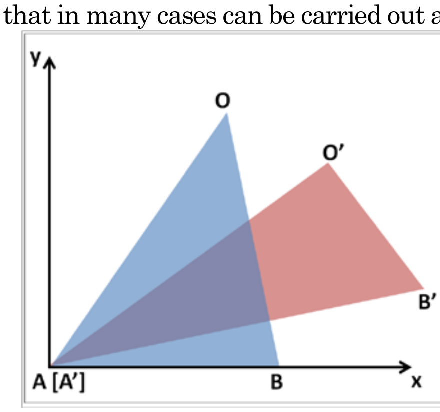

Figure 1. (Color online) the area-preserving transformation from triangle *AOB* (blue) to *AO'B'* (green) along both *x* and *y* directions.

Consider a general two-dimensional (2D) affine coordinate transformation $x' = ax + by + c,\ y' = dx + ey + f$, from triangle AOB to $A'O'B'$ in the x-y plane, as shown in Fig. 1. The associated Jacobian matrix is $\overline{\overline{J}} = [a,b;d,e]$. For transverse magnetic (TM) modes where the H field is perpendicular to the x-y plane, we obtain the transformed relative dielectric permittivity and permeability as $\overline{\overline{\varepsilon}}' = \overline{\overline{J}}\,\overline{\overline{J}}^T / \det(\overline{\overline{J}})$, $\mu' = 1/\det(\overline{\overline{J}})$. We can achieve unitary permeability μ' by imposing a unitary Jacobian $\det(\overline{\overline{J}}) = 1$ [14]. The geometric interpretation is that the transformation is area-preserving, such that the area of the triangle AOB is always equal to that of $A'O'B'$.

As a special case ($\angle AOB = 90^o$) of the horizontal shear area-preserving (No transformation imposed along y direction) transformation (APT), we introduce the application of a 2D surface plasmonic (SP) resonator based on transverse magnetic (TM) bending adapters. Its APT method is illustrated in Fig. 2(a). The rectangular region $AOBC$ is a part of a rectangular planar waveguide. To form one arm of the bending adapter, we transform ΔAOB to the new triangle $\Delta AO'B$, where the angle α is the half-bending angle of the adapter. The final bending angle is 2α , formed by mirroring the structure with regard to axis BO', as shown in the inset figure. Without loss of generality, we set length $|OB|=1$, and fix the point A on the horizontal axis at location $(-L, 0)$. To impose the nonmagnetic condition we require that the area of triangle AOB should equal that of $AO'B$. Thus, O' should be placed such that $OO' // AB$, *i.e.* $x_{O'}+Ly_{O'}=0$. The Jacobian is thus unitary, leading to $\mu'=1$. An equilateral polygonal resonator can be formed by using multiple bends under the condition $p2\alpha=2\pi$ [Fig. 2(b)], where p is an integer. Furthermore if metallic material such as silver is placed in the center, SP resonance can be excited at the interface between metal and dielectrics [15-17], as shown in Fig. 2(c).

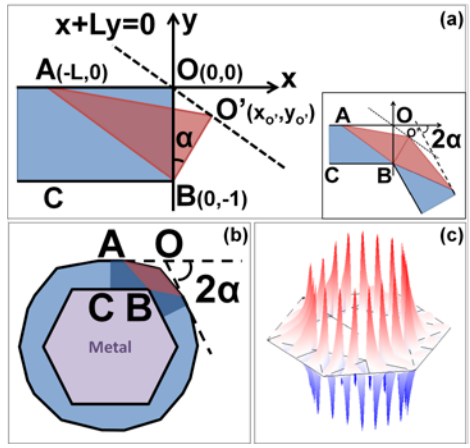

Figure 2. (Color online) (a) APT (from ABO to $AB'O'$) for one arm of the bending adapter. (b) A transformation optics based polygonal resonator formed by multiple bending adapters. (c) The distribution of magnetic field of a transformation optics based SP hexagonal resonator.

In summary, based on the transformation optical design which possesses simultaneously unitary permeability and piece-wise homogeneity, transformation-optics devices can practically avoid magnetism and inhomogeneous parameters, and be implemented directly using existing dielectric materials with ideal performance.

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