Wavelength-dependent Optical-rotation Manipulation for Active Color Display and Highly Secure Encryption

Maowen Song[1,3], Alexander V. Kildishev[1,2], Di Wang[1,2], Zhuoxian Wang[1,2], Yi Xuan[1], Alexandra Boltasseva[1,2], Honglin Yu[3], and Vladimir M. Shalaev[1,2,*]

[1]*Birck Nanotechnology Center, Purdue University, West Lafayette, IN 47907, USA*
[2]*School of Electrical and Computer Engineering, Purdue University, West Lafayette, IN 47907, USA*
[3]*Key Lab of Optoelectronic Technology and Systems of Education Ministry of China, Chongqing University, Chongqing 400044, China*
Author e-mail addresses: hlyu@cqu.edu.cn, shalaev@purdue.edu,

Abstract: We present a silica coated aluminum metamirror with wavelength-dependent optical rotation effect. Excitation of localized surface plasmons maps discrete polarizations into diverse colors, broadly increasing the encoded information space.

OCIS codes: (250.5403) Plasmonic; (330.1720) Color vision; (130.5440) Polarization-selective devices;

1. Introduction

Plasmonic nanostructures have been used recently to scatter light of different colors depending on their geometry and composition. Plasmonic color filters are becoming popular because they have higher resolution, are more environment-friendly, and mechanically/chemically robust in comparison to conventional organic dyes or pigments. Numerous investigations have been carried out to enhance their color tunability by incident polarization. For example, the design of asymmetric optical antennas [1-3] has enabled polarization-dependent plasmonic color filters which doubled the information states per nanopixel [4]. However, the rapid development in the area of data storage and security calls for extra tuning parameters to increase levels of information states. This motivates the current study of a plasmonic color filter with wavelength-dependent optical rotation.

2. Results and Discussion

We present a dynamically switchable plasmonic color filter based on surface texturing of aluminum slab covered with 200 nm thick silicon dioxide (silica) layer. Figure 1(a) illustrates the schematic of the metamirror and its function as plasmonic color filter. Different colors from the incident white light can be filtered out upon reflection by rotating the reflected polarizer (Φ_r), with incident polarizer (Φ_i) fixed at diagonally polarized angle with respect to the x direction. This is caused by plasmon induced wavelength-dependent optical rotation effect. The period of the structure is 160 nm with the optimized dimensions of each nanoantenna l = 110 nm, w = 50 nm, and t = 40 nm (Figure 1(a)). The calculated polarization-dependent reflectances for all four combinations of the polarization states are depicted in Figure 1(b).

Figure 1(c) shows the phase difference between two x and y polarizations as a function of the wavelength. Polarization states corresponding to some special bands have been plotted, demonstrating the optical rotation effect. Figure 1(d) demonstrates the calculated reflectance with the reflected polarizer varying from 0^o to 165^o with a step of 15^o when the incident light is diagonally polarized. The colors corresponding to different combinations of incident and reflected polarizations are calculated using the simulated reflectance spectra and the color-matching functions. The color palette of this structure is shown in Figures 1(e) and (f).

Importantly, our technique can be designed for highly secure information encryption. For example, five kinds of basic elements (Figure 2) are put together to form the layout, achieving a higher security level. A special combination of incident and reflected polarizations acts as a decoding key to decrypt various information states, namely ‘BNC’, ‘NANO’, as shown in the images in Figure 2. We note that the information can be reversibly encrypted through rotating polarizer, which is much faster than the method proposed in [5].

3. Summary

We proposed a dynamically tunable color filter based on wavelength-dependent optical rotation effect. Careful arrangement of differently oriented nanoantenna can be used to further increase the encoded information states and achieve highly secure encryption. Our technique offers promising platforms for applications in active color displays, high-density optical data storage, security tagging and cryptography.

This work was supported in part by Air Force Office of Scientific Research MURI Grant (FA9550-14-1-0389). M. S. would like to acknowledge the Chinese Scholarship Council (CSC, No.201606050044) for financial support. A. V. K. wants to acknowledge support from the DARPA/DSO Extreme Optics and Imaging (EXTREME) Program.

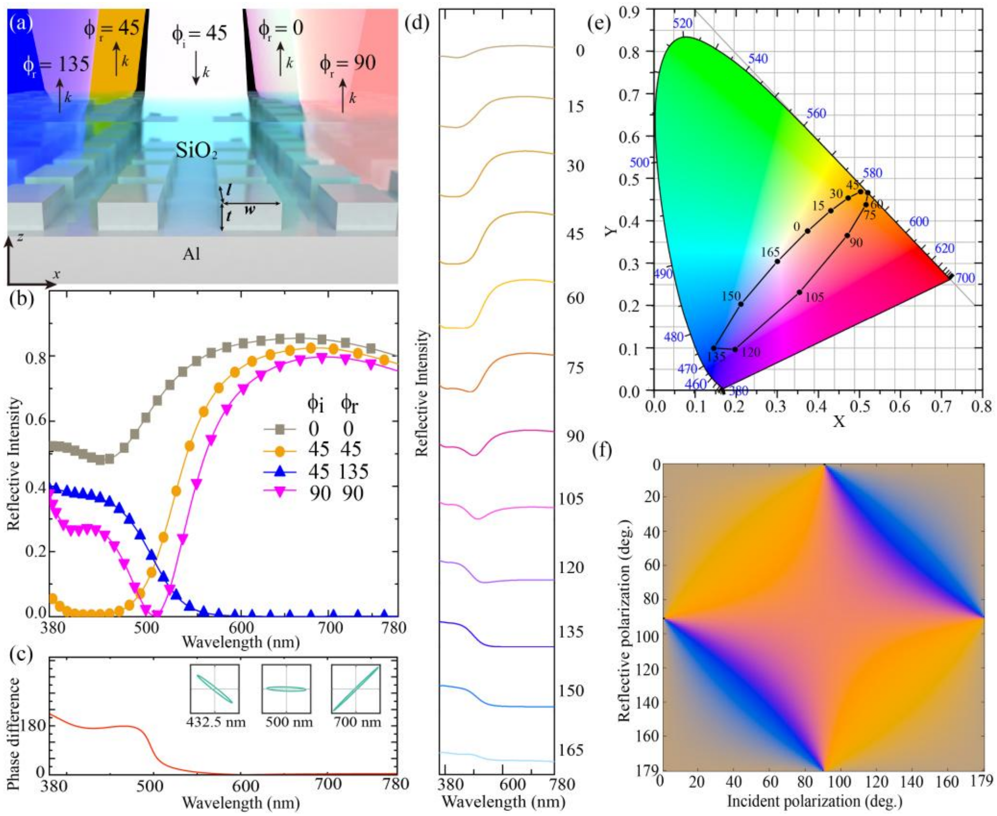

Figure 1. Mapping different polarization states of light to visible colors. (a) Schematic diagram of the light-structure interaction process. The output color results from mixing of the four distinct colors. (b) Simulated reflection spectra correspond to the four distinct colors generated by different combinations between incident and reflected polarization states. (c) The wavelength-dependent optical rotation effect. (d) Diagonally polarized white light is chromatically filtered out by rotating the reflected polarizer. (e) Each spectrum in (d) is mapped to a single point and connected to a cylinder trajectory covering a wide range on the CIE 1931 xy chromaticity diagram. (**f**) A view of the color palette can be achieved via different combinations between incident polarization and reflected polarization. Different curves in (b) and (d) are colored according to the RGB values transferred from their spectra data using our Matlab script.

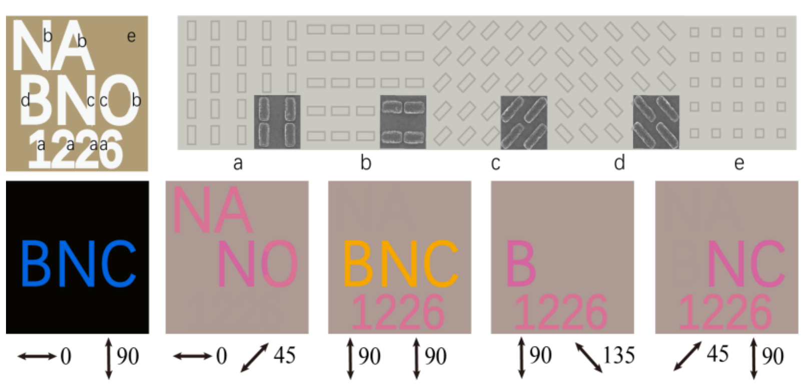

Fig. 2. Highly secure information encryption. Different building blocks (indicated by a-d) are generated by rotating the nanoantenna with a step of 45^o. Squared nanoparticles are used as the background of the layout (e). The insets show the scanning electron microscope images of fabricated antennas. The bottom row shows calculated images decrypted by 5 different combinations of polarization states from the same layout shown in top left image.

4. References

[1] Z. Li, A. W. Clark, and J. M. Cooper, ACS Nano **14,** 493-498 **(2016)**.
[2] T. Ellenbogen, K. Seo, and K. B. Crozier, Nanolett. **12**, 1026-1031 **(2012)**.
[3] M. Song, X. Li, M. Pu, Y. Guo, K. Liu, H. Yu, X. Ma, and X. Luo, Nanophotonics **7,** 323-331 **(2018)**.
[4] K. Kumar, H. Duan, R. Hegde, S. C. W. Koh, J. N. Wei, and J. K. W. Yang, Nat. Nanotech. **7**, 557-561 **(2012)**.
[5] X. Duan, S. Kamin, and N. Liu, Nat. Commu. **8**, 14606 **(2017)**.