Asymmetric Color Appearance with Aluminum Plasmonic Substrates

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We demonstrate tilted nanostructured aluminum lamellas showing asymmetric optical appearance [1]. In particular they show a switch from colorless to colorful transmission. Such an effect is very valuable for applications in optical security. The fabrication of the structure utilizes the earth abundant aluminum and is compatible to roll-to-roll processes thus allowing cost-efficient large-scale production.

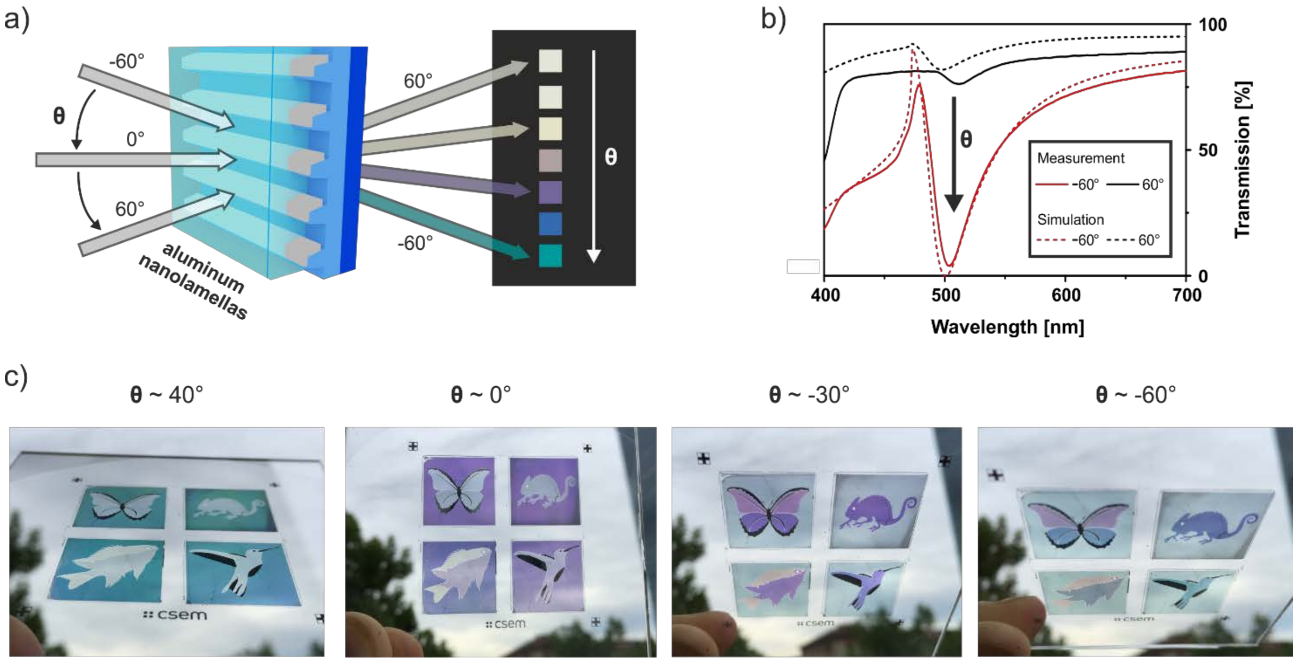

Figure 1: (a) Scheme of the plasmonic structure rendering distinct colors at varying incident angles θ of the light. The patches show the measured colors upon polarized light of different substrates. (b) Measured and simulated transmission spectra at +60° and -60° tilt angle. (c) Photo of a sample at different tilt angles in unpolarized daylight. The sample contains animals with structural colors in nature. The different optical appearance is achieved by variation of the evaporation angle.

In recent years, the interest in plasmonics and especially their potential applications has strongly increased. Plasmonics describes the collective oscillation of electrons on metal structures interacting with incident light. This can cause absorption or reflection in specific spectral ranges of the incident light, leading to colorful transmissions or reflections. Such so-called structural colors can be used for various applications such as optical security devices or active tunable filters.

We demonstrate plasmonic substrates with asymmetric optical appearance based on geometrical tilted aluminum nanostructures (see Figure 1a). Upon certain viewing angles we observe a strong color filtering property, which changes with variation of the angle (e.g. blue at -40°, green at -60°). In contrast observing the structure from the other tilting direction does not show any colored transmission. The great difference in transmission is shown in Figure 1b, where the red curve shows a very narrow resonance dip at about 500 nm for negative angles. This is caused by strong coupling of a plasmon resonance and a propagating resonance, depending on the shape of the aluminum and the period of the structures respectively.

The color filtering properties of the structure can be tuned with the nanostructure's geometrical parameters. We fabricate such structures by transferring a pattern of periodic nanostructures into polymers or sol-gel, by evaporating aluminum at a specific angle and finally by embedding the structure with a polymer or a sol-gel. Variation of the evaporation angle leads to distinct geometry of the aluminum nanolamellas directly influencing the color filtering properties. The final embedding step is crucial for anti-counterfeiting applications since it prevents direct copy of the structure and protects the structure from scratches and dirt enabling use at ambient conditions (Figure 1c). The fabrication method is compatible for roll-to-roll processes and high-throughput fabrication.

Figure 1c shows a demonstration of such a plasmonic device designed for optical security [2]. The sample was made at different evaporation angles for each sample areas (e.g. butterfly). Thus different colors appear at distinct tilt angles of the design. A complete switch between colored background and animal structure is observed within less than 10° tilt angle. The proposed effect is not based on diffractive effects. Therefore it is clearly visible in unpolarized and diffused light (challenging with classical holograms based on diffraction).

[1] L. Duempelmann, D. Casari, A. Luu-Dinh, B. Gallinet and L. Novotny, ACS Nano 9 (12) (2015) 12383–12391.

[2] G. Basset, *et al.*, patent pending, (2015).