Dynamic Control of Plasmonic Colors by Voltage Actuation MEMS Cantilevers

Zhengli Han, Christian Frydendahl, Noa Mazurski, Uriel Levy
Department of Applied Physics, the Hebrew University of Jerusalem, Jerusalem, 9190401, ISRAEL
Author e-mail address: han.zhengli@mail.huji.ac.il

Abstract: We propose a dynamic control of plasmonic colors by using MEMS (micro electro mechanical system) cantilevers. The nano hole structures provide plasmonic colors, while the MEMS cantilevers are built on top to switch the colors. © 2021 The Author(s)

1. Introduction

Recently, plasmonic color based on the metallic nano structure resonances has become a hot topic due to several advances, such as fine resolution in display, permanent life time, etc [1,2]. Dynamic controls of plasmonic colors have also been demonstrated with approaches of liquid crystal [3], chemical gas [4], and geometry structure reconfiguration [5]. However, control approaches by voltage that can be potentially compatible with the mature techniques of integrated circuit and CMOS process are still in challenge. In this work, we propose a dynamic control of plasmonic colors of nano hole array by using MEMS (micro electro mechanical system) [6] cantilevers with voltage actuation and experimentally demonstrate the operation of such cantilevers.

2. Dynamic control of plasmonic colors

Figure 1 schematically shows the proposed concept of this work. A cantilever is built on top of a nano hole array. The cantilever can be actuated by applying voltage to the electrodes, where one electrode is connected to the cantilever itself and another electrode is connected to the nano hole array underneath. The nano hole arrays can have different sizes such that they can work as a bandpass filter of red, green and blue (RGB) separately when white light is shining on the device from above. When the cantilever is closed by applying voltage, the bandpass filter has no output, and thus the transmission will display a dark color. By controlling individually each of the cantilevers, the transmission would have display of RGB or combination of RGB similar to that of the current liquid crystal display, but with a much lower power consumption because of the low power consumption of MEMS voltage actuation.

The size of MEMS cantilever is about 50 µm, which intrinsically determines the mechanical resonant frequency of about few kilo hertz and the action speed around micron second. Thus, it should be fast enough for a display usage.

We use a double-layer metallic nano hole array for the bandpass filter design, as shown in Fig. 2. The double-layer has an advantage of narrowing the spectra to a desired color compared to a single layer. For polarization independent operation, the nano hole is a round circle, and the chosen diameters for the blue, green and red color filters are 144 nm, 200 nm and 300 nm respectively. For the red case, we insert a nano disk with diameter of 120 nm inside the nano hole to suppress the higher modes, such that the transmission spectra would be mostly centered around the red color.

Fig. 1: Schematic of the proposed device.
The metal is aluminum (Al) and the dielectric spacer between the double metal layers is silicon oxide (SiO$_2$), so as the substrate (not shown) in simulation. We have calculated the transmission through the structure using Lumerical FDTD with periodic boundary condition. The results are presented in Fig. 2(d), showing very clearly the three colors.

Fig. 2: Design of the red, green and blue bandpass filters. (a-c) Schematic of the double-layer nano structure designs. (d) Simulated transmission spectra.

Following the simulations, we have fabricated the MEMS cantilevers as shown in Fig. 3. We are now in the process of integrating the nanoholes with the cantilever, as will be reported in the talk. During the cantilever fabrication process, we used photoresist as the sacrificial pattern and it was released by oxygen plasma. Since the cantilever has bilayer composition of Al and SiO$_2$, after release the material inner tensions lead the cantilever to a tilt shape. The amount of tilt amount is controlled by the thickness of the materials, which are now being adjusted to a proper value taking into consideration the tradeoff between actuation voltage and light transmission. The nano hole arrays are implemented using electron-beam lithography and lift-off processes.

Fig. 3: Fabricated MEMS cantilevers.

3. Summary

In summary, we have proposed a dynamic control of plasmonic colors of nano hole arrays by using MEMS cantilevers with voltage actuation and fabricated the cantilevers. The final device is under construction. Its fabrication and characterization results will be presented during the talk.

References

[1] Soroosh Daqiqeh Rezaei, Zhaogang Dong, et al. “Nanophotonic Structural Colors,” ACS Photonics 2020, XXXX, XXX, XXX-XXX
[2] J.S Clausen, E Højhund-Nielsen, AB Christiansen, S Yazdi, M Grajower, et al, “Plasmonic metasurfaces for coloration of plastic consumer products.” Nano letters 14 (8), 4499-4504 (2014).
[3] Franklin, D., Chen, Y., Vazquez-Guardado, A. et al. “Polarization-independent actively tunable colour generation on imprinted plasmonic surfaces,” Nat Commun 6, 7337 (2015).
[4] Duan, X., Kamin, S. & Liu, N. “Dynamic plasmonic colour display,” Nat Commun 8, 14606 (2017).
[5] Holsteen, A. L.; Cihan, A. F.; Brongersma, M. L. “Temporal Color Mixing and Dynamic Beam Shaping with Silicon Metasurfaces,” Science 365 (6450), 257– 260 (2019).
[6] Zhengli Han, Kenta Kohno, Hiroyuki Fujita, Kazuhiiko Hirakawa, and Hiroshi Toshiyoshi, “MEMS reconfigurable metamaterial for terahertz switchable filter and modulator,” Optics Express, 22(18), 21326-21339 (2014).