بهبود عملکرد فیلترهای رنگی پلاسمونی مبتنی برنانوحفره‌ها برای استفاده در سنسورهای پردازش تصویر CMOS

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چکیده – فیلترهای رنگی در کاربردهایی همچون سنسورهای پردازش تصویر CMOS، صفحه نمایش‌های کریستال مایع و دیودهای ساطع‌کننده نور نقشی کلیدی بازی می‌کنند؛ استفاده از نانوحفره‌های پلاسمونیکی برای تحقق اینگونه فیلترها، از مزایای مهمی از جمله هماهنگی با تکنولوژی CMOS برخوردار است. در این مقاله مجموعه‌ای از فیلترهای رنگی (قرمز، سبز و آبی) با استفاده از یک آرایه مربعی متناوب از نانوحفره‌ها بر روی ورقی از آلومینیوم و زیرلایه سیلیکا طراحی شده است که برای استفاده در سنسورهای CMOS مناسب هستند. با وجود سادگی ساختار و ملاحظات صورت گرفته برای هموار کردن فرآیند ساخت، مشخصه نوری این فیلترها از پیک انتقال ۳۰ تا ۶۷ درصد و پهنای باند نصف توان ۴۰، ۵۰ و ۱۰۵ نانومتر به‌ترتیب برای فیلترهای قرمز، سبز و آبی برخوردار است. این در حالی است که طول موج رزوناس رنگ‌ها نیز با دقت بالایی محقق شده است. علاوه براین میزان تداخل رنگی با درنظرگرفتن یک لایه اضافی سیلیکا به عنوان سرپوش، تا حد قابل قبولی کاهش یافته است.

کلید واژه- فیلترهای پلاسمونیکی رنگی، نانوحفره، انتقال غیر عادی نور، سنسورهای پردازش تصویر CMOS، پلاسمون پلاریتون‌های سطحی

Performance Enhancement of Nanohole Array-based Plasmonic Color Filters for CMOS Image Sensors

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Abstract- Color filters play a key role for applications like CMOS image sensors, liquid crystal displays and light emitting diodes. Using a nanohole array as a plasmonic color filter offers important advantages, in particular compatibility with CMOS processes. In this paper, a set of primary filters (red, green and blue) consisting of a square-lattice of sub-wavelength holes in an aluminum film and a silicon dioxide substrate are presented for employing in CMOS image sensors. Despite their simple structure and ease of fabrication, the results have shown a transmission peak of 30-67 percent with a FWHM of 40 nm, 50 nm and 105 nm in accurate wavelengths of red, green and blue, respectively. Furthermore, reducing the cross-talk of the filters is investigated by utilizing a silicon dioxide overlay to enhance the coupling of SPPs at both sides of the aluminum film.

Keywords: Plasmonic color filters, Nanohole array, Extraordinary transmission, CMOS image sensors, SPPs

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1 Introduction

The optical properties of an opaque metal film perforated with a periodic array of sub-wavelength apertures has led many researchers to work on the extraordinary optical transmission (EOT) phenomenon in these structures. The first observation provided evidence that such metallic nanohole array shows an unexpected optical response so that the transmission of light in certain frequencies is greatly more than what expected classically. This is related to the excitation of SPPs[1] propagating along the interface of metal and insulator due to its periodically patterned surface, just the same as a grating [1, 2]. In order to compensate the difference between the wave-vector of SPP and the wave-vector of light in free space, a periodic array of tiny holes can be used to provide the additional required momentum. By satisfying the Bragg condition, the position of maximum transmission within the square lattice of a nanohole array can be estimated. The enhanced optical transmission of metallic nanohole arrays is a promising approach to create plasmonic color filters (PCFs) for various applications [3-5].

Since 2003, several different designs of these PCFs have been demonstrated. The proposed filters are not highly selective and the minimum full-width at half-maximum (FWHM) presented is about 50 nm. Although the bandwidth of the transmission spectrum for some of these filters is small, they suffer from high cross-talk due to the multiple transmission peaks [6].

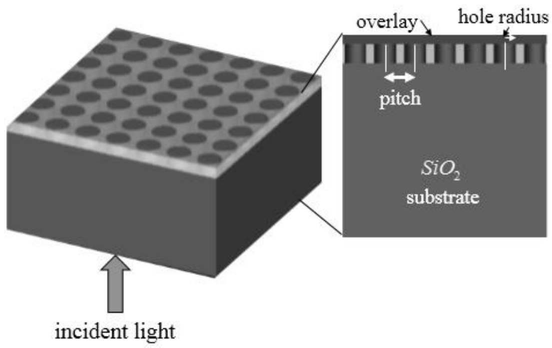

Figure 1: A schematic and cross-section of the proposed filters at the final step of the design process

In this paper, a simple method is proposed to design filters with maximum transmission response and low color cross-talk at red, green and blue wavelengths, respectively. Moreover, improving the performance of plasmonic color filters by utilizing a SiO_2 overlay is investigated.

2 Filter Design and Simulation Process

In order to achieve RGB filters for CISs[2], silicon dioxide is employed as substrate, and aluminium as the metal film due to their compatibility with CMOS processes and the low cost of aluminium comparing with gold or silver. Filters were designed by perforating the metal film with a square array of circular holes (as demonstrated in Figure 1), due to its easier fabrication compared to the square or cross-shaped one.

[1] Surface Plasmon Polaritons

[2] CMOS image sensors

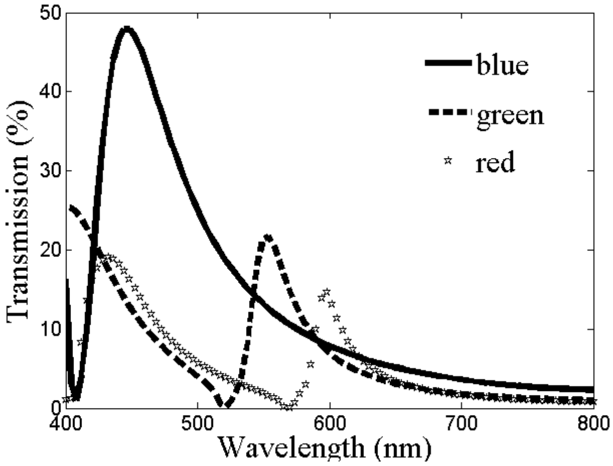

Figure 2: The transmission responses of the three primary filters at the first step of the design process

Our designs also include another restriction to enable a single step lithography cycle: the same metal thickness and also the same dielectric overlay are used for all the red, green and blue filters for simplicity.

2.1 Method and Results

At the first step, a nanohole array was formed on top of the SiO_2 substrate by perforating a 100 nm aluminium film with a square lattice of holes. The pitch of the arrays are 388 nm, 355 nm and 276 nm for the red, green and blue filters, respectively. The simulated transmission responses for the filters of the first step are shown in Figure 2 (The radius of hole is 100 nm). The centre wavelength of the color filters are located approximately at 445 nm (blue), 555 nm (green) and 600 nm (red).

The transmission spectra of the filters exhibit a small FWHM for all the filters. However an unwanted transmission peak in the red and green filters would cause a conspicuous cross-talk. Although the blue filter can be seen to have a good transmission response with a 48% transmission peak and a FWHM of about 80 nm, the red and green filters are not desirable according to their high amount of cross-talk.

Figure 3 depicts the near-field intensity distributions on top of the holes, for the green filter. As shown, the near fields are stronger at the rims of the holes. In order to enhance the coupling of SPPs at both sides of the metal film, we have

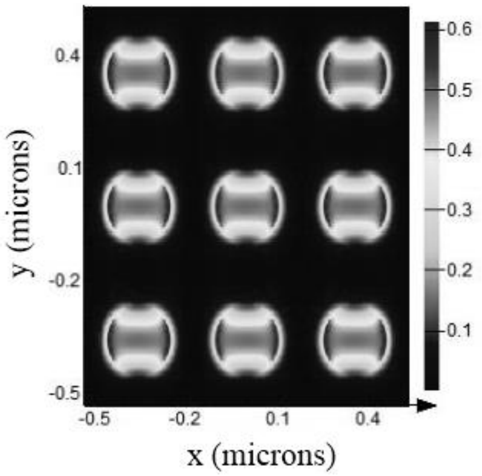

Figure 3: The near-field intensity distributions on top of the apertures (the green filter)

-investigated the effect of a SiO_2 overlay with different thicknesses. The results for the green filter are presented in Figure 4. As it can be seen, it is possible to reduce the multiple transmission peaks and the cross-talk by using a SiO_2 cap layer on top of the metal film. As shown, a half thickness of the metal film is good for the overlay thickness. The near field intensity of the green filter with a 50 nm cap layer shows the enhanced coupling of the top and bottom resonances as expected (see Figure 5).

The simulated RGB filters with a 100 nm hole radius, a 100 nm aluminium film and a 50 nm SiO_2 overlay is depicted in Figure 6. Maximum transmission for the red, green and blue filters are 30%, 43% and 67% with a FWHM of 40 nm, 50 nm and 105 nm, respectively.

Conclusion

In this work, we have proposed a progressive design method to obtain plasmonic color filters with an accurate resonant wavelength, a relative high transmission and a low FWHM to improve the color selectivity of such filters. Furthermore, suppressing undesirable sub-peaks and therefore achieving a low color cross-talk were explored by investigating the effect of an overlay SiO_2.

As a practical result, a set of RGB filters for CISs have been designed and simulated with Lumerical FDTD software. For this goal, silicon dioxide was

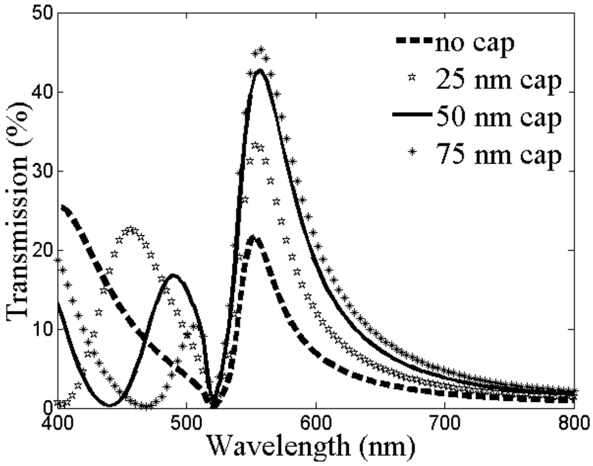

Figure 4: The effect of cap layer on the green filter of the first step

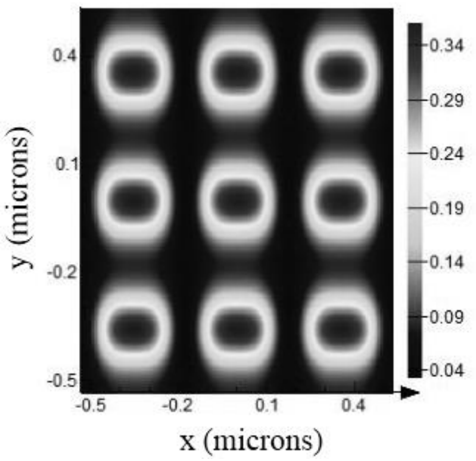

Figure 3: The near-field intensity distributions on top of the apertures (for the green filter with a 50 nm overlay)

-used as the substrate to make the fabrication easy. The chosen metal for the design is aluminium due to its compatibility with CMOS processes, and also a good adherence to silicon dioxide in addition to its low cost. Since it is much easier to create a circular tiny hole in the metal film comparing with square or cross-shaped apertures, the filters have been obtained by a periodic array of circular holes in a square lattice.

In order to simplify the fabrication, we have used the same metal thickness and overlay enabling a single step lithography cycle. Despite their simplicity and ease of fabrication, the results have shown a transmission peak of 30-67 percent with a FWHM of 40 nm, 50 nm and 105 nm in accurate resonant wavelengths of the colour filters.

These facts demonstrate the suitable optical response of the proposed filters for using in CMOS image sensors.

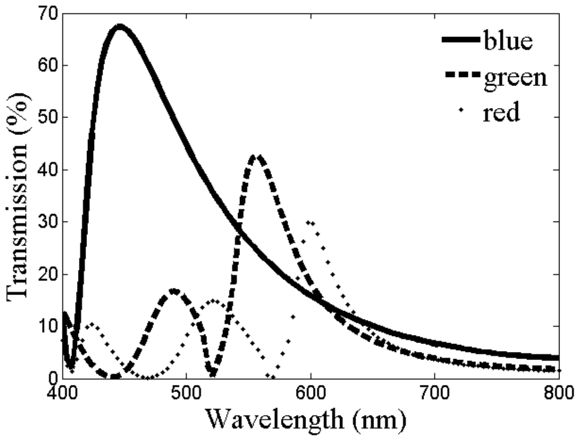

Figure 6: The transmission response of the three primary filters at the second step of the design process (using a 50 nm silicon dioxide overlay) for red, green and blue lights

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