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# Color Selective Design for Quantum Dot Infrared Photodetectors

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## 1. Introduction

In atmosphere, the electromagnetic wave can transmit in two wavelength ranges, i.e. 3-5 and 8-12μm. In order to detect these signals, different types of detectors have been developed. The quantum dots infrared photodetector (QDIP) is one of the best choices. QDIP has the advantages of higher temperature operation, normal incidence and wide detection range [1], etc. To detect these two ranges of EM wave, the metal film perforated with periodic hole array on the backside of the QDIP is proposed [2]. The backside metal design is not adequate for a focal plane array (FPA) to detect multi-color simultaneously. So that the top metal contact designed with cross metal holes which have high transmission ratio because of the x y direction coupling effect [3,4] is proposed in this paper. The cross-hole top metal can be served as the top contact and optical filter at the same time.

Surface plasmons (SPs) were widely explored in the field of surface science following the pioneering work of Ritchie in the 1950s [5]. In 1998, Ebbesen et al. reported that metal films perforated with two-dimensional subwavelength periodic hole arrays exhibit extraordinary optical transmission because of SP resonance [6,7]. Afterwards, the SPs properties have attracted much interests due to their potential applications in subwavelength photolithography, near-field microscopy, wavelength-tunable filter, optical modulators [8, 9].

## 2. Experiments

The QDIP with wide detection range, i.e., 4 to 11μm, is fabricated on the (100)GaAs substrate. It consists of a 5 multiple 42nm undoped GaAs/8nm $In_{0.15}Ga_{0.85}As$ /InAs QDs /50nm undoped GaAs/ InAs QDs layers with 50nm undoped GaAs, 300nm n-GaAs top contact and 600nm n-GaAs bottom contact doped with Si concentration $2\times10^{18}$. as shown in Fig. 1. The device contains two detection windows, LWIR (8-11 μm) and MWIR(4-8 μm). LWIR detection wavelength is contributed by dot in well (DWELL) and MWIR detection wavelength is contributed by quantum dots (QDs). The cross pattern on top contact metal is defined using Elionix ELS-7500 e-beam lithography system. Afterwards, 300nm-thick Au/Ge/Ni alloy and 700nm-thick Au metal film are thermally deposited and lifted off to form the periodic cross hole arrays. The schematic structure of the device is shown in Fig. 2(a). Fig. 2(b) shows the scale representation and SEM images of the hexagonal cross holes. Metal arrays with different periods and hole sizes as listed in Table I are fabricated. The array parameters are chosen to match the wavelength window of the QDIP.

## 3. Results and Discussion

For normally incident light through the hexagonally arranged metal holes, the peak wavelength $\lambda_{sp}$ of the plasmon can be expressed as

$$\lambda_{sp} = a[\frac{4}{3}(i^2 + ij + j^2)]^{-1/2}(\frac{\varepsilon_d \varepsilon_m}{\varepsilon_d + \varepsilon_m})^{1/2} \quad (1)$$

$\varepsilon_d$ and $\varepsilon_m$ are the dielectric constants of the dielectric material and metal, respectively, i, j are integers, a is the lattice constant. For GaAs wafer $\varepsilon_d$ equals to 12.76 at 300K. For a=1.1, 1.6 and 2.8μm, the peak wavelength which can be seen in Figs. 3 and 4 will appear roughly at 3.41, 4.96 and 8.67μm, respectively. Fig. 4 shows the transmission spectrum with hexagonal cross hole array and the FTIR DTGS detector responsivity spectrum measured by Bruker IFS 66 v/s FTIR system. The inset in Fig. 4 is 2-20μm spectrum detected by the FTIR DTGS detector. From Fig. 4, it is convinced that hexagonal cross hole metal layer is not only the top contact but also the optical filter.

The measurement of QDIP and QDIP with cross hole metal top contact structure are shown in Fig. 5 at 20K under the bias of -2 volt with normally incident IR light. The hexagonal cross hole is designed using lattice constant, a = 2.8μm, L=2μm W=2μm. It is obvious that the peak is 8.4μm which approaches the theory 8.67μm and only 8-11μm range EM wave can propagate through the cross holes. It is evident that designing the top contact with cross holes on the QDIP can achieve color selective device successfully.

## 4. Conclusions

Using the extraordinary transmission phenomenon of the surface plasmon, the wide band QDIP with 4-11μm detection bandwidth can realize the color selectivity simultaneously or individually by using cross hole array on top metal contact layer. It can be applied to fabricate the FPA. The cross hole top metal contact serves not only as contact but also the optical filter and provides extra area to let much light going through compared with no cross holes shape.

Table I Device parameters of three cross hole arrays

| Cross shape parameter | Peak (theory) (μm) | Peak (measured) (μm) |
|---|---|---|
| a = 1.1, L = 0.7, W = 0.3 | 3.41 | 3.52 |
| a = 1.6, L = 1, W = 0.4 | 4.96 | 5 |
| a = 2.8, L = 2, W = 0.8 | 8.67 | 8.9, 8.6 |

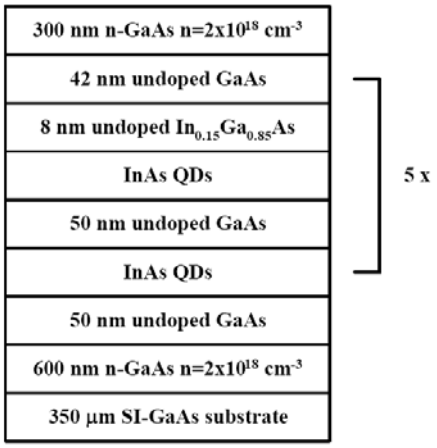


Fig. 1. The wide band (4-11µm) quantum dot infrared photodetector structure with dots in InGaAs/GaAs well and quantum dots, two parts.

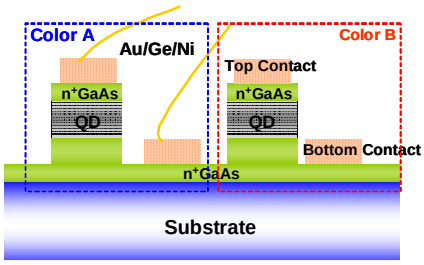


Fig. 2(a). The schematic structure of the device of QDIP structure with cross hole top metal contact.

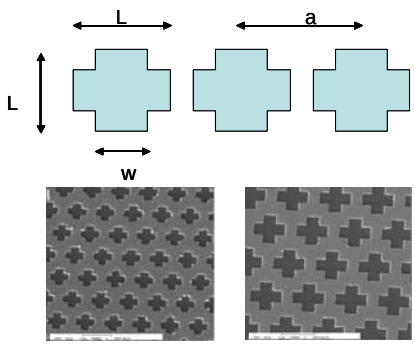


Fig. 2(b). The cross shape scale representation and the SEM images for a = 1.1µm (left) and a = 2.8µm (right)

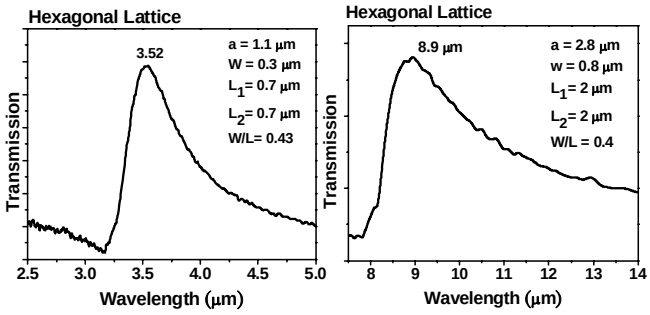


Fig. 3. The transmission spectra of cross hole shape for a=1.1µm and 2.8µm the peak position is 3.52µm and 8.9µm, respectively.

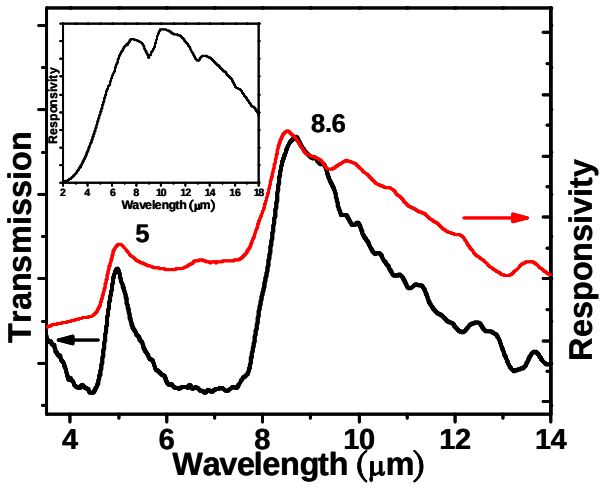


Fig. 4. The transmission spectrum of cross hole shape for a=1.6µm and 2.8µm, simultaneously, and the responsivity of the FTIR DTGS detector with 2-25µm IR light transmit through the hexagonal cross hole shape. The inset is the DTGS responsivity without cross hole shape.

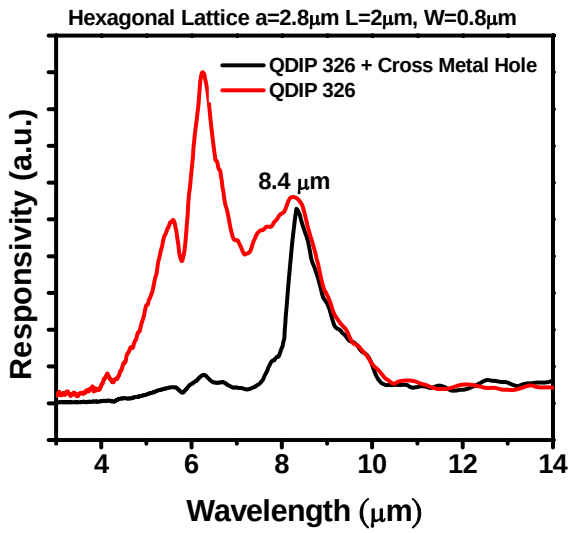


Fig. 5. The responsivity spectrum of QDIP with and without cross hole shape at 20k under the bias of -2 volt.

## References


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