行政院國家科學委員會專題研究計畫　期中進度報告

兼具偵測多波段紅外線及可見光的偵測器陣列模組之研發

(2/3)

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兼具偵測多波段紅外線及可見光的偵測器陣列模組之研發
計畫編號：NSC 92-2215-E-002-022
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一、中文摘要

本計畫預期完成兼具偵測多波段紅外線及可見光的偵測器陣列模組。其主要工作內容包含三部分：單一偵測器的設計與製作、偵測器陣列的設計與製作、讀出電路的設計與製作，最後是偵測器陣列與讀出電路的整合。

在單一偵測器方面，我們所要完成的偵測器，不但具有偵測不同紅外線波段輻射強度的能力，而且能遙測物體溫度。該偵測器的基本結構是：兩種不同的超晶格結構，而其中夾著一寬能障。兩超晶格具有不同的電子躍遷能階，故能偵測不同波段的紅外線。而中間的寬能障，可作為電子能量的高通過濾器，具有調變偵測器響應的功能。利用二種不同的偵測器響應，我們可求出光電流的比值，由此遙測出輻射物體的溫度。

在偵測器陣列方面，我們針對超晶格偵測器的特性，設計出可正面入射的像素 (pixel) 。其中每一像素的表面，均有 V 型的凹槽，以解決該偵測器正向入射的問題；另在像素 mesa 的側面，均覆蓋著絕緣體及金屬層，這是為了反射光線及防止表面漏電流而設計的。如此的陣列設計，可增加捕光的能力，又能防止像素間的串訊，另具防止表面漏電流等多重功能。本計畫的陣列是以一維的線性陣列為重心。

在讀出電路方面，我們針對紅外線陣列的需要，設計出相配的讀出電路。其中以 correlated doubled sampling circuitry 來減除重置雜訊。並以差動放大器將亮訊號減去暗訊號，以增加讀出電路的零敏度。在製作讀出電路的同時，我們也將利用 CMOS 技術製作可見光偵測器，以期使整個模組兼具偵測多波段紅外線及可見光的能力。

我們長期的目標在於完成熱影像攝影系統。而本計畫則以線性陣列模組為近期的工作項目，預計以三年的時間完成。

二、本年度計畫緣由與目的

Superlattices have been demonstrated previously by our group in the design of the multicolor infrared photodetector. In general, the period number of the superlattice may be up to several dozens. In this project, we have investigated the performance of the infrared photodetectors especially with 3, 5 and 15 periods. The detector structure contains a thick blocking barrier embedded between two superlattices with different period numbers but with the same well and barrier widths. This double-superlattice structure shows switchable spectral responses between two spectral regions by the voltage polarities. The photoresponse in each spectral region is also tunable by the magnitude of the applied voltage. The voltage-dependent behavior reveals the photoelectron relaxation and transport mechanism in the superlattice miniband. Superlattice with few periods has high electron group velocity, less relaxation effect and less collection efficiency. Therefore the superlattice with few periods may have better responsivity and narrower photoresponse range than the one with many periods. Based on the experimental results of our devices, it is observed that the superlattice infrared photedetector with fewer periods has better detectivity, responsivity, wider range of the operational temperature, and more flexible miniband engineering than the conventional multiple quantum well infrared photodetector.

三、執行進度

Figure 1 is the comparison of spectral response of Sample A **(SLIP with 3-period and 5-period)** under positive and negative bias. In order to identify the relationship between spectrum and bias voltage, we plot spectra with high bias and low bias separately. From Fig. 1, the photoresponse peaks range from 6.7 to 7.4 μm under applied voltage 0.4 to 0.6V. These relative short wavelength responses are mainly due to the high-energy photoelectron above the barrier height of the blocking layer. With increasing voltage, the long wavelength response dominates the spectrum. It is attributed that the photoelectrons in the lowest state of second miniband can tunnel through the barrier with the assistance of the strong electric field at high biases. For the applied voltage>1.0V, the spectrum has a peak at about 9.0 μm and the lineshape is insensitive to bias voltage. In the same way, the spectral response under negative bias, i.e. corresponding to the top superlattice, ranges from 6.7 to 7.5 μm under the low bias of -0.4 to -0.7V and has a long wavelength peak at 9 μm under negative bias>0.9V. It is obvious that the photoresponse of the two superlattices can be tuned by the bias magnitude due to the energy filter effect of the blocking layer.

It is observed from Fig. 1 that no matter under low or high bias, 3-period SLIP has higher responsivity than 5-period SLIP. Because of the wider miniband range, the photoresponse of 5-period superlattice is a little bit boarder than the one of 3-period superlattice. This characteristic is more obvious especially under high bias.

The peak detectivity D* at 20K is 3.7×10^{10} $cmHz^{0.5}/W$ under 1V and 9μm, and 2.35×10^{10} $cmHz^{0.5}/W$ at 9μm under -1V. This result also shows that 3-period SLIP has the better detectivity than 5-period SLIP. Because the temperature of background limited performance is 70K for Sample A, we also estimate the value of detectivity at 80K. The D* at 80K is 7.16×10^{8} $cmHz^{0.5}/W$ under 1.3V and 6.53×10^{8} $cmHz^{0.5}/W$ under -1.3V. Because of the rapid increasing of dark current at high temperature, the detectivity decreases as the temperature raising.

Figure 2 shows the spectral response of Sample B **(SLIP with 3-period and 15-period)** under positive and negative bias. The solid lines are the photoresponses under positive bias for the 3-period superlattice and dashed lines are the ones under negative bias for the 15-period superlattice. The response is dominated by short-wavelength transition under low bias and shift to long wavelength as voltage increasing just like Sample A. Under positive bias, the main peak is at 6.7μm when bias < 0.9V and the peak at 7.8μm appears at higher bias. For bias > 1.3V, the main peak is at 9.35μm and the lineshape of the responsivity does not vary with the bias voltage anymore. For negative bias, the main peak is 6.65μm at low bias and is 9.5μm under high bias. The effect of the blocking barrier, i.e. the voltage tunable spectrum, is also observed in Sample B.

By comparison between solid and dashed lines, some characteristics are observed. Firstly, except under low bias, 3-period superlattice has the narrow photoresponse range while 15-period superlattice has the broader one. Secondly, under 1.2V, three responsivity peaks such as 6.5μm, 7.8μm and 9.1μm can be distinguished clearly. These three peaks can approximately correspond to three energy levels formed by 3-period superlattice. Thirdly, from Fig. 2 (b) and (c), the superlattice with few period numbers still has the better responsivity for long wavelength response and for short wavelength response, the superlattice with many period numbers has the better performance.

Assuming the shot noise behavior, the peak detectivity D* is 9.33×10^{10} $cmHz^{0.5}/W$ under V=1.7V at wavelength 9.4μm and

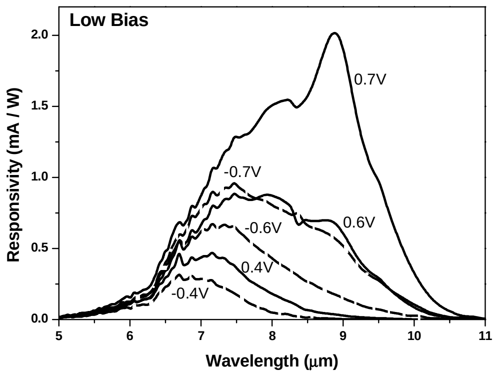
4.96×10^9 cmHz$^{0.5}$/W for V=-1.6V at 6.7μm. At T=80K, the D* is 1.88×10^9 cmHz$^{0.5}$/W for V=1.8V at 9.4μm and 1.31×10^9 cmHz$^{0.5}$/W for V=-1.6V at 6.7μm. It is observed that at 80K, 15-period superlattice detectivity at short wavelength is better and 3-period superlattice detectivity at long wavelength is better.

Because the transit distance of few-period superlattice may be short, the absorption coefficient can not be measured in our experiments. Because of the better absorption coefficient, photoresponse at short wavelength range of many-period superlattice may be better. Hence the period number of superlattice is a factor we have to tune for the optimum performance. Although the low absorption coefficient is a drawback for few periods superlattice, we still consider the few period superlattice is a better structure for SLIP because of its high responsivity, detectivity and operational temperature at long wavelength range.

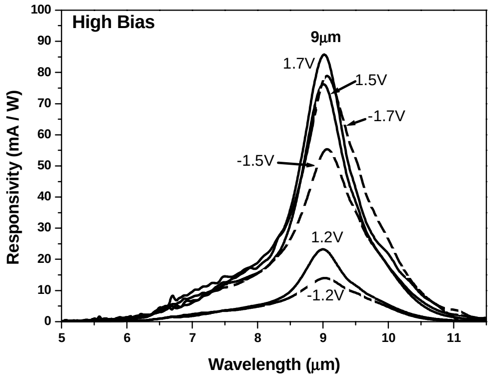
四、總結

We have compared the experimental results of SLIPs with different period number. By changing the polarity of bias, the different SLIP in one sample can be operated. The current blocking layer in SLIP structure can act as an energy filter and make the photoresponse tunable. Few-period superlattices have characteristics such as higher group velocity, less relaxation effect but lower absorption coefficient. For Sample A, although the period numbers of the two superlattices are so close that the I-V characteristics are almost the same, the better responsivity of the 3-period one than that of the 5-period one can still be identified. In Sample B, because of the higher group velocity, we can see the better electric and optical properties in 3-period superlattice than in 15-period one. Based on our experimental results, it is concluded that a superlattice with few periods has better responsivity, detectivity and higher operational temperature.

五、圖表及註解

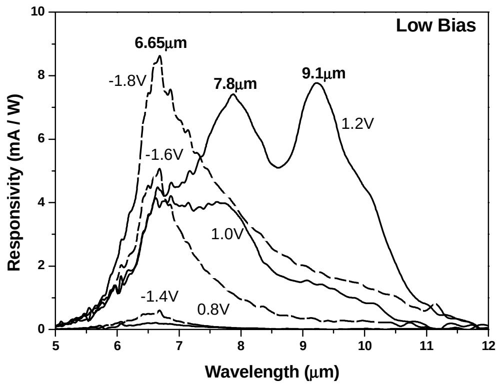


(a)

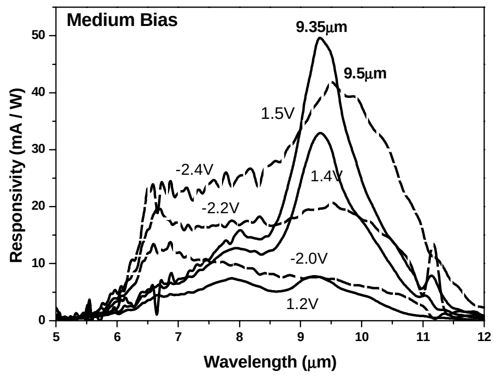


(b)

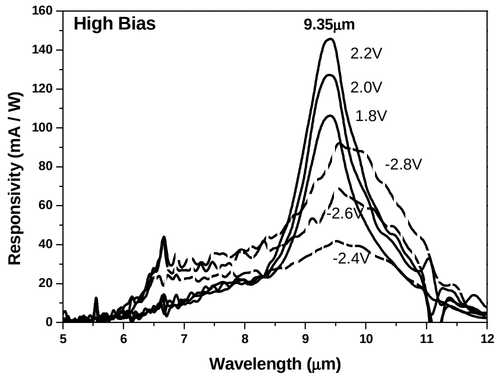
Figure 1 The comparison of responsivity of sample A under positive and negative biases at (a) low biases and (b) high biases. The solid lines are responsivity under positive biases and dashed lines are the responsivity under negative biases. The 9μm responsivity is suppressed at low bias, while it increases with the applied voltage increasing.



(a)



(b)



(c)

Figure 2 The responsivities of sample B with (a) low bias magnitude, (b) medium bias magnitude and (c) high bias magnitude of both positive and negative biases. The solid lines are responsivity under positive biases and dashed lines are the responsivity under negative biases. The peak responsivity is shifted from short to long wavelength as biases increasing.

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