WAVELENGTH SELECTIVE DETECTION USING EXCITONIC RESONANCES IN GaAs/AlGaAs P-I-(MQW)-N STRUCTURES

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The quantum confined Stark effect causes a strong wavelength and voltage dependence of photocurrent near excitonic resonances which is used to study the wavelength selectivity of p–i(MQW)–n photodiode. For a parallel input of optical bits each coming at a different wavelength, the selectivity is considered good if the state of a λ_i wavelength bit can be detected regardless of the λ_j ($j \neq i$) state of the bits. Photocurrent is found to have very good selectivity if λ_j bits are all zero, i.e. the optical information is serial. However, we find that differential photocurrent ($\Delta I_{ph}/\Delta V$) provides a good selectivity for random states of λ_j bits (i.e. parallel input). Four channel selectivity is demonstrated at 200K. Specially designed quantum well structures can greatly improve this selectivity.

Fiber optic communication systems offer the possibility of very large bandwidth allowing information to be carried in many different wavelengths, without interference. Unfortunately, this capability is very difficult to utilize since most detection schemes can not accurately decode a particular wavelength when information is also randomly coming in at other wavelengths. Approaches to solve this difficulty involve techniques where selected wavelengths are allowed to transmit (using various tuned filters) while others are blocked, or through use of more complex coherent detection schemes[1]. While these approaches are certainly important, the technology will greatly advance if the detectors themselves display wavelength selectivity. The optical detectors such as a photodiode is not expected to display wavelength selectivity. In most applications the tunable range of the energy of the photons would be $\leq$ 100 meV, where most detectors have a uniform response.

The photocurrent versus voltage characteristic of a reverse biased p–i(MQW)–n structure is known to exhibit strong wavelength dependence[2,3] due to the heavy hole (HH) and light hole (LH) excitonic peaks and their dependence on electric field – the quantum confined Stark effect (QCSE)[4]. This dependence can be exploited to develop tunable detectors. Such a scheme works quite well, as we shall discuss below, if the optical information comes in serially at different wavelengths. However, if the information comes in parallel, the photocurrent is unable to unravel the information contained in a given wavelength. We discuss in this letter a scheme to carry out selective detection with information impinging randomly in parallel.

P-i-n detectors for our experiments were grown by molecular beam epitaxy (MBE). The i-region consists of 100 periods of multiquantum well consisting of alternate layers of 100 Å GaAs and 100 Å $Al_{0.3}Ga_{0.7}As$. 500-μm diameter mesa diodes are defined by photolithography and appropriate ohmic contacts are formed on the p- and n-sides by evaporation and annealing. The wavelength dependence of the photocurrent-voltage characteristics was measured by using the output of a tunable dye laser in the range 800 - 870 nm and a HP 4145 parameter analyzer.

In Fig. 1(a), we show the room temperature reverse biased photocurrent of the p–i(MQW)–n diode for a series of wavelengths of equal intensity. As can be clearly seen, even at room temperature, at a given bias value the photocurrent is quite distinct for different wavelengths. Using this structure with an external series resistance (load line shown in Fig. 1(a)) we see that the voltage across the p–i–n structure has a strong wavelength dependence. Results in Fig. 1(b) are shown for 200 K. At room temperature, a change in input wavelength of 100 Å produces a change in the output reference voltage of ~ 10V. If the input information is

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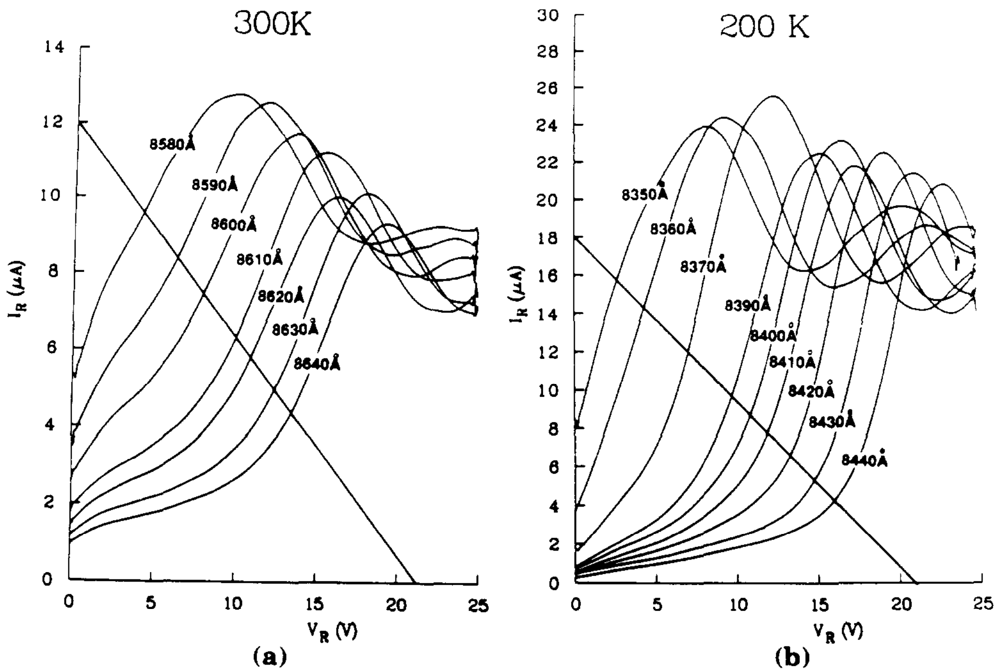

Figure 1 Measured photocurrent-voltage characteristics at various wavelengths in a p-i(MQW)-n photodiode (a) at 300 K and (b) at 200 K.

coming serially, the output reference voltage in the circuit provides a very selective determination of the state (ON or OFF) of the chosen wavelength. This scheme will allow one to detect up to 50 wavelength channels serially, allowing a reference voltage across the resistor to vary by ~ 0.2 V.

While the serial detection of a given wavelength may be useful for many applications, in communication, one would like the detectors to selectively detect information in a channel at wavelength λ_i regardless of the state of the channel at wavelength λ_j $(j \neq i)$. The photocurrents shown in Figs. 1(a) and 1(b) are not capable of doing this as can be easily seen by summing various λ_i curves. However, if two p–i–n structures are biased at voltages V_i and $V_i + \Delta V_i$, a simple subtraction of the currents provides the value of $\frac{\Delta I_{ph}}{\Delta V}$. In Fig. 2 we show this scheme of operation. To study the "parallel" selectivity of this device we show in Figs. 3(a)-(d), the values of $\frac{\Delta I_{ph}}{\Delta V}$ at 200K as a function of voltage, when information is coming in through four channels at wavelengths 8350 Å, 8370 Å, 8410 Å and 8430 Å. The light curves in each diagram, for a selected λ_i, represent the results of $\sum_{j\neq i} \frac{\Delta I_{ph}(\lambda_j)}{\Delta V}$ for all possible (2^3 -1) combination states (i.e. ON or OFF) of the other

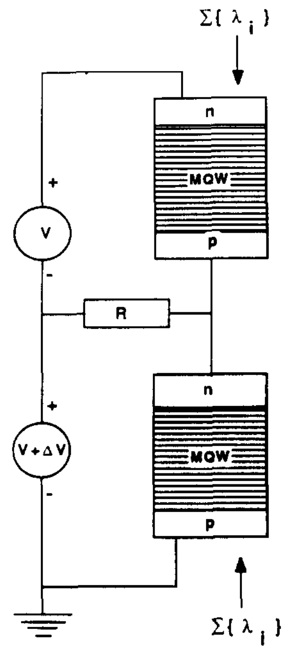

Figure 2
Schematic for photocurrent subtraction using two diodes for wavelength selective detection. The potential developed across the resistance R is proportional to the differential photocurrent.

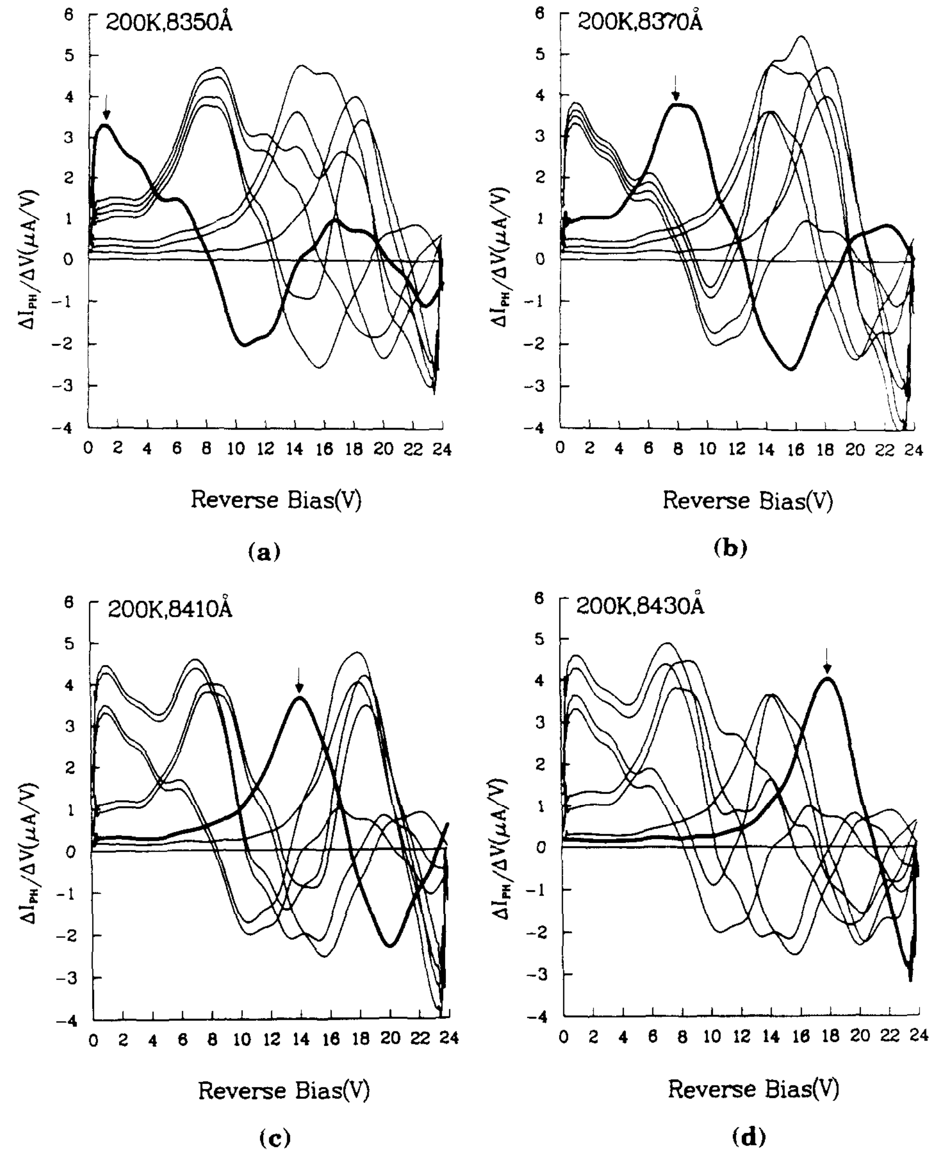

Figure 3 Values of $\Delta I_{ph}/\Delta V$ at 200 K for different states of 4 channels λ_j. The bold current represents the ON state of λ_i only when $\lambda_1 = 8350$ Å (a), 8370 Å (b), 8410 Å (c), and 8430 Å (d).

($\lambda_j \neq \lambda_i$) channels. The bold line represents the value of $\frac{\Delta I_{ph}(\lambda_i)}{\Delta V}$ for the case where only channel λ_i in ON.

From the results of Fig. 3, we see that if the difference current obtained from two p-i(MQW)-n diodes of Fig. 2 biased at values 1 V apart is compared with a constant current source of appropriate value (2 μA for our results) the state of the channel λ_i can be detected regardless of the state of the other channels, if the devices are biased in the region indicated by the arrow. For example, in Fig. 3(a) shown for λ_i = 8350 Å, if the diodes are biased at 2.0 $\pm$ 0.5 V, the difference current is more than 2 μA if the λ_i bit is ON and less than 2 μA if it is OFF regardless of the states of the other channels. The same holds for 8370 Å if the diodes are

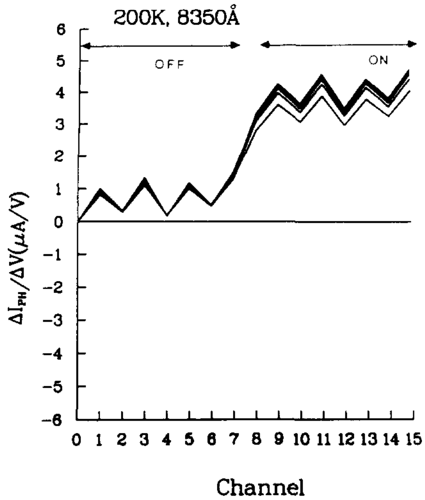

Figure 4
Values of $\Delta I_{ph}/\Delta V$ at 200 K plotted against the binary word representation of all four wavelength channels. The most significant wavelength here is λ_i = 8350 Å.

biased at 9.0 ± 0.5 V and for 8410 Å at 14.0 ± 0.5 V and for 8430 Å at 18.0 ± 0.5 V. The results are represented in a different way in Fig. 4. Considering the case of four incoming wavelength channels, each channel is assigned a digit in a binary four-bit word, the most significant bit being the wavelength λ_i which needs to be detected. For the other three wavelengths λ_j ($\neq \lambda_i$) a bit in the word is 1 if that particular λ_j is ON and 0 if it is OFF. The abscissa represents the binary state of the channels which are 2^4 in number. Hence, whenever λ_i is ON, the channel number is greater than 7. Results in Fig. 4 are shown for λ_i = 8350 Å with the diodes biased at 2.0 ± 0.5 V. The vertical axis is the differential change in photocurrent. The different curves in the diagram correspond to different biasing voltages around the optimum value as indicated in the plots of Fig. 2. It is clear that within a small incremental range of voltages (± 0.5 V) the differential photocurrent jumps from 1.5 μA/V to 4 μA/V as the most significant channel λ_i is turned ON. Similar results are obtained for other values of λ_i.

From our studies we find that with operation at 200 K four channel parallel information can be easily decoded. Also examining the value of the photoresponse, we see that an important source of non-selectivity in this scheme comes from the negative resistance region of the I–V response. If this region were not present, the selectivity is estimated to increase to ~ 30 channels. We are now pursuing the fabrication of p–i(MQW)–n structures where the i–region consists of multiquantum wells with two different well sizes so as to eliminate the negative resistance region and allow decoding of a layer number of channels. In summary we have shown that while the photocurrent in a p-i(MQW)-n structure has a very high wavelength selectivity, it can operate usefully only if the optical information is impinging serially. In that case by preadjusting a comparator voltage, the presence or absence of the given wavelength signal can be efficiently detected. If however, the information is impinging in parallel, differential photocurrent is more useful. A simple scheme proposed by us can carry out efficient decoding when information is coming in four wavelengths simultaneously.

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