W-T1-B5

Modeling and Optimization of GaAs/AlGaAs MQW Surface Reflection All-Optical Switches

Yong-Ho Choi and Woo-Young Choi
Department of Electronic Engineering, Yonsei University
Shinchon 134, Seodaemoon, Seoul, Korea

Introduction

There is a growing interest in semiconductor all-optical switches that are compact and fast, and can be deployed in a massively parallel manner. Such semiconductor all-optical switches are expected to find wide applications in future all-optical switching network systems [1]. Among many semiconductor all-optical switches, our interest lies in surface reflection type switches utilizing optical nonlinearity in multiple quantum wells (MQWs). One such device has been demonstrated to have femtosecond-switching time with a very high on/off ratio [2]. In this paper, we analyze the switching performance dependence on switch structures and operating conditions.

Figure 1 shows a schematic of the surface reflection all-optical switch investigated in this paper. When the probe beam propagates in the switch without the pump beam, it is absorbed by MQWs. This is the OFF-state. But with the pump, MQWs are saturated and the probe passes through the switch. This is the ON-state. In order to realize a practical switch, the switch should have a large ON-state signal and a small OFF-state signal. The goal of our investigation is realization of the optimal switch structure and operating conditions.

Multiple Quantum Well Modeling

The investigated MQW structure has 75 Å thick GaAs wells and 100Å thick AlGaAs barriers. GaAs/AlGaAs quantum wells were chosen since their optical constants are easily available and many experiments has been done on them [3,4]. Our analysis can be equally applied to switches made of other materials such as InGaAs/InP MQWs. The absorption spectrum of MQWs was calculated including exciton effects. For excitonic absorption, Wannier model for 1-s state exciton was used [5]. For exciton linewidth broadening with increasing carrier concentrations, linear dependence was assumed [6,7]. Figure 2 shows the absorption spectra when the pump power increases from 0 to 1200W/cm^2 in steps of 200W/cm^2. Excitonic absorption peaks are clearly observed at low pump densities but they disappear at high pump densities. Figure 3 shows the reduction in absorption at each pump density from the unpumped case. Clearly, the probe wavelength should be selected at the value where $\Delta\alpha$ is maximum.

Analysis of the Switch Output

In order to determine the optimal quantum well number, the change in probe transmission with and without the pump is calculated for structures with different quantum well numbers. The result is shown in Figure 4. The pump power density of 1200W/cm^2 is used for all cases. With a small number of qunatum wells, the ON-state probe output signal is high as the absorption region is short but for the same reason, the OFF-state probe output is high. Consequently, the change in transmission is small as shown in the figure. With a large number of quantum wells, much of the probe beam is absorbed both at the ON- and OFF-state. Consequently, the change in transmission is again small. This clearly shows that there exists an optimal quantum well number in which the change in probe transmission is maximum. In our case, quantum well number of 36 gives the largest change as shown in the Figure 5.

One method of reducing the OFF-state probe signal without affecting the ON-state signal is using a DBR mirror having low reflectivity on top of the switch [2]. The DBR mirror can cause destructive interference between two probe signals and, significantly reducing the OFF-state probe output. At ON-state, the out of phase condition is no longer valid and the DBR mirror does not affect much. The effect of an additional DBR mirror can be shown in Figure 5 where 5% DBR mirror was used. It is shown that the DBR mirror significantly reduces the OFF-state signal without affecting ON-state signal much. Details of our analysis will be presented at the conference.

Conclusion

We have studied the nonlinearity of GaAs/AlGaAs MQWs and calculated the absorption spectrum. The results agree well with the experiments [3,4]. We modeled all-optical switch using it. With a given pump power, we determined the optimal number of MQWs having the maximum transmission change. And we improved the ON/OFF ratio of the switch output using DBR mirror. In addition, we analyzed a switch structure with DBR mirror that has improved ON/OFF ratio.

Reference

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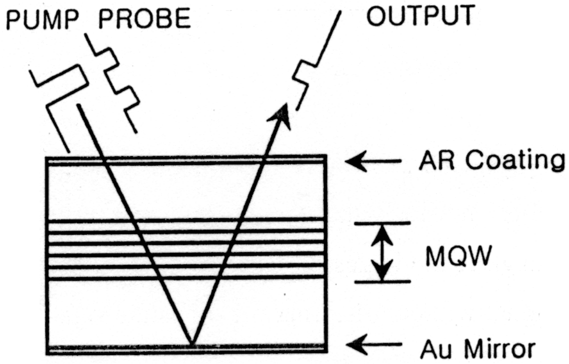

Fig.1 Surface reflection all-optical switch using multiple quantum wells.

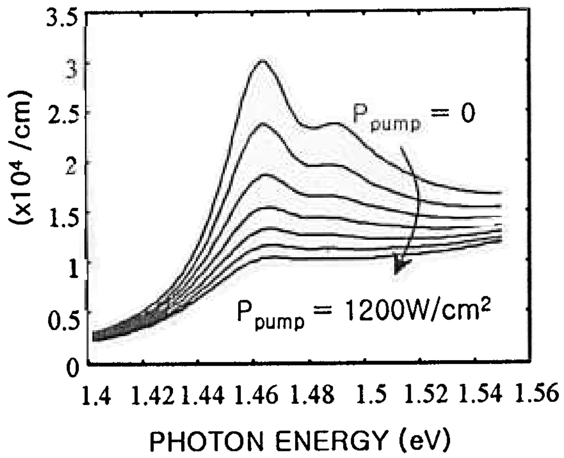

Fig.2 Absorption spectrum of GaAs/AlGaAs multiple quantum wells

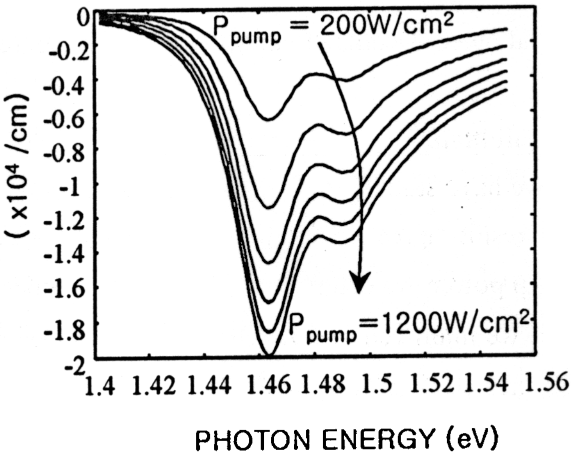

Fig.3 Reduction in absorption at various pumping power densities

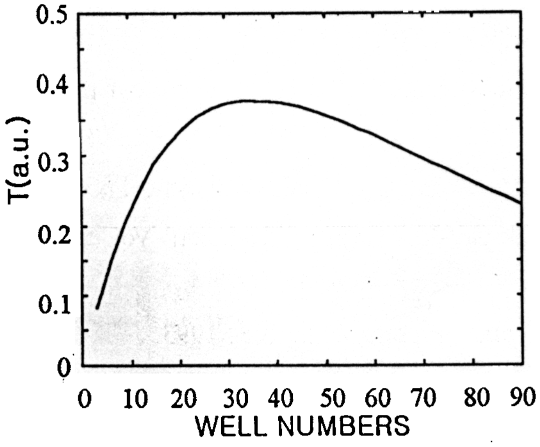

Fig.4 Change in transmission as function of quantum well numbers

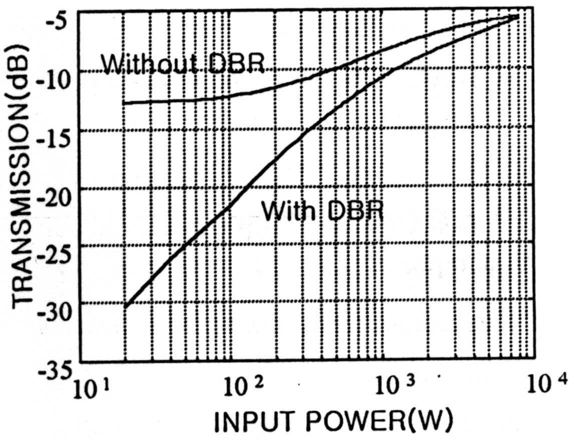

Fig.5 Enhancement of transmission with addition of DBR