Femtosecond All-Optical AND Gates Based on Low-Temperature-Grown Be-Doped Strained InGaAs/InAlAs Multiple Quantum Wells

R. Takahashi, W.-Y. Choi, Y. Kawamura*, and H. Iwamura
NTT Opto-Electronics Laboratories
3-1 Morinosato Wakamiya, Atsugi-Shi, Kanagawa, 243-01 Japan

Ultrafast all-optical AND gates are of great importance for future ultrahigh-speed optical communication networks. Several types of such devices have been realized using optical nonlinearities in various materials. Those based on semiconductors [1- 3] are especially attractive as they, with their compactness, have advantages for practical applications. In this paper, we present a new type of a semiconductor-based all-optical AND gate that we believe has the fastest response time and the highest contrast ratio as well as the widest operation wavelength range among all the semiconductor-based all-optical AND gates reported to date.

Our device utilizes the carrier-induced absorption change with subpicosecond recovery time achieved in low-temperature-grown Be-doped InGaAs/InAlAs MQWs [4]. The layer structure for the device used in the present study is shown in Figure 1 with the substrate side on the top. The device is a surface-reflection-type device and both pump and probe beams enter from the substrate side. The sample was grown at 200°C by gas-source MBE. One percent compressively strained InGaAs wells and lattice-matched InAlAs barriers were both doped with $7.8\times10^{17}\mathrm{cm}^{-3}$ Be, and have a room-temperature absorption peak for transitions between heavy-hole (HH) and conduction bands at about 1.54μm. Although the total thickness over 2μm for the strained InGaAs wells is more than the usual critical thickness for strain relaxation, our device does not suffer from strain relaxation because of its low growth temperature. Compressively strained MQWs require fewer carriers for absorption saturation because light-hole (LH) and HH bands are split, and only the HH band with greatly reduced density of states is active for transitions around 1.55μm. The InGaAsP/InP DBR mirror with 1% reflectivity enhances the nonlinear reflection characteristics of the device. This is because the reflected light from the DBR mirror can cancel out, by destructive interference, most of the reflected light from the Au mirror when (and only when) input light intensity is small. Furthermore, the device is polarization insensitive to probe light when excited by the linearly polarized pump because of the spin states of excited carriers. Details of nonlinear-reflection and polarization-dependence characteristics of the device can be found in [5].

The gating behavior of our device was investigated using pump-probe measurements. A commercially available optical-parameter-oscillator provided short optical pulses with auto-correlation FWHM of about 200 femtoseconds. Figure 2 shows the fastest resulting probe-reflectivity response with the pump-probe wavelength at 1.535μm. The gating time determined from the probe response FWHM is 250 femtoseconds, which can be further reduced if shorter optical pulses are used. The contrast ratio, defined as the ratio of the peak reflectivity to the background level, is 26 at the pump energy of 10 pJ. This contrast ratio is much larger than those for other semiconductor-based AND gates [1-3].

The contrast ratios and peak probe reflectivities were further investigated as functions of pump-probe wavelength (Figure 3) and pump energy (Figure 4). The contrast ratio peaks at around 1.54μm where the change in absorption is largest, whereas the peak probe reflectivity tends to increase at longer wavelengths where absorption tails off. As can be easily seen from the figure, our AND gate can be operated over 30 nm and still maintains more than half of the maximum contrast ratio. Such a wide operational wavelength range has never been observed in any other ultrafast AND gate, and is not

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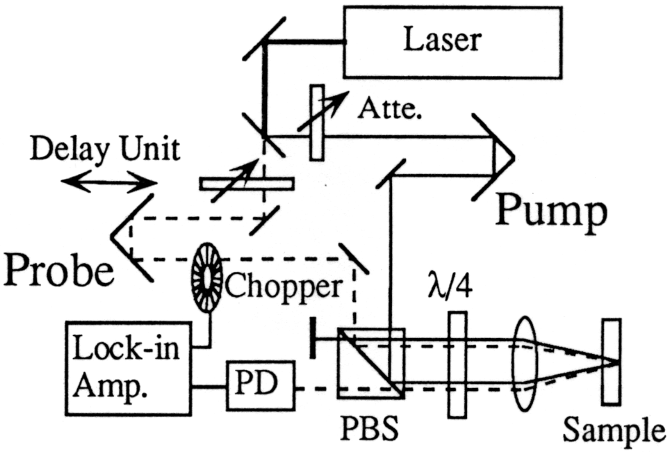
[*] Now at Osaka Prefecture University, Osaka, Japan.



測定系

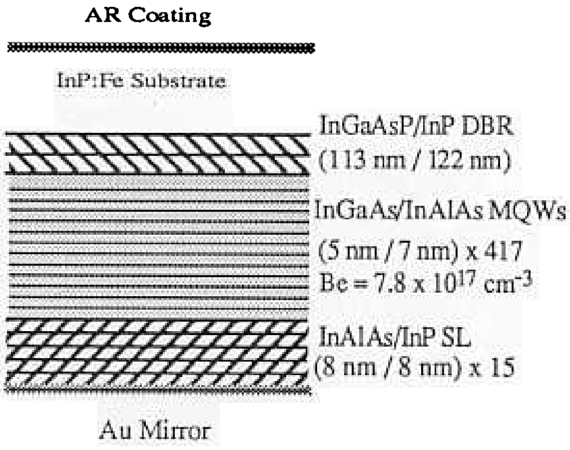
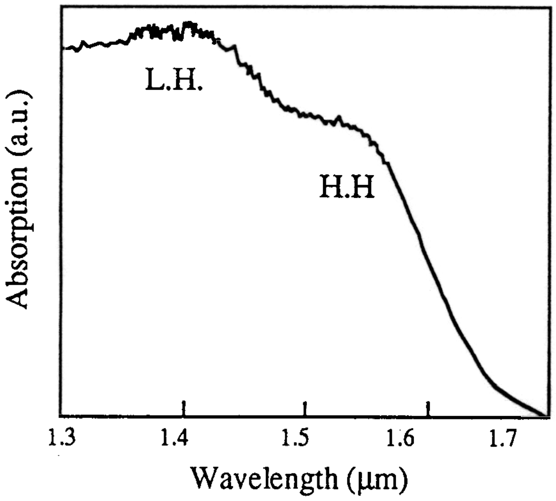


図２　素子構造



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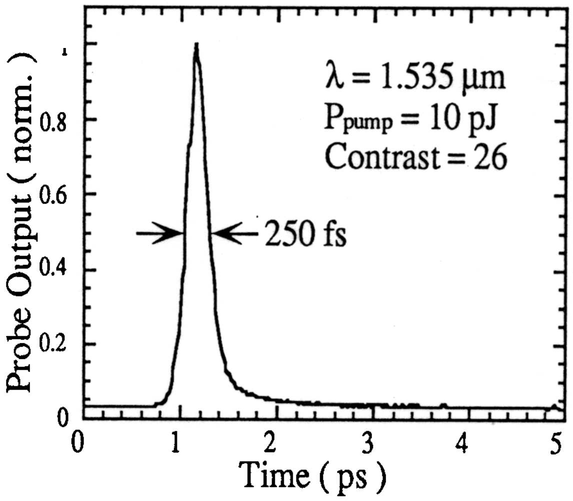

図４　光ゲートの時間分解波形

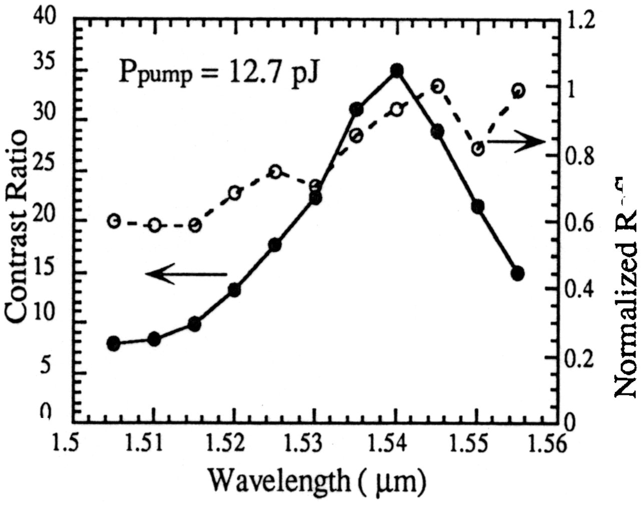

図５　光ゲートの波長依存性

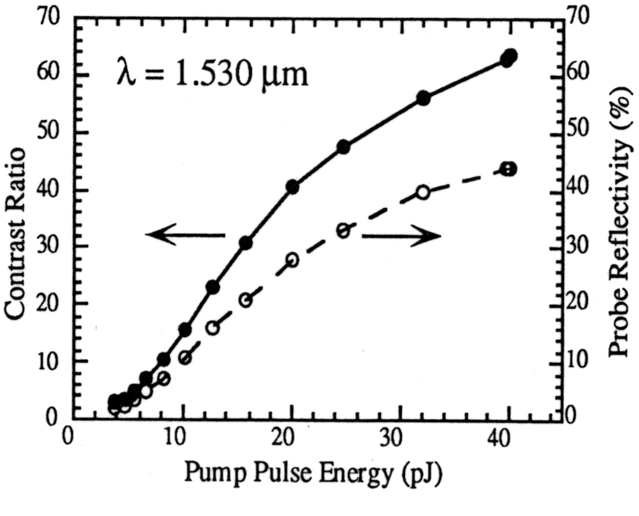

図６　光ゲートの励起光強度依存性