PS-7-12

Extended Abstracts of the 2012 International Conference on Solid State Devices and Materials, Kyoto, 2012, pp244-245

# Room Temperature Excitonic Electroabsorption Effect for High-Speed and Low-Driving Voltage Spatial Light Modulators

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## 1. Introduction

There is considerable interest in surface normal modulators for high-speed, wide-band, and parallel processing optical interconnection technology. Surface-normal modulators are most useful in applications where a fairly high-density of outputs is desired. Since it is easy to fabricate two-dimensional arrays, surface-normal modulators can be formed as spatial modulators, which can be used for many interesting switching and optical signal processing applications [1, 2]. A spatial light modulator was reported by use of the electroabsorption (EA) effects in a GaAs single crystal [3]. Though this is the first report on a semiconductor spatial modulator, a frame rate is slightly higher than 500 Hz and operating voltage was 4 kV. Therefore, there has been a strong demand for optically addressed spatial light modulators with high response speed and high contrast ratio with a small operating voltage for a long time. A key technology is high purity crystal growth with large depletion thickness [4].

We have succeeded in growing ultrahigh purity GaAs layers by a liquid phase epitaxial method where residual impurity concentrations are of the order lower than $10^{13}$ $cm^{-3}$ and electron mobility are of the level of 200,000 $cm^2$/Vs at 77K [5]. These epitaxial layers give large depletion width over 30 μm at 0 V and show clear excitonic absorption peak at room temperature [6], resulting to highly efficient surface-normal modulators with a high contrast ratio of over 25 dB and the operating voltage of 32 V. However, the window diameter (300 μm) is too wide to reach-through upto 26 V.

In this paper, we propose a new spatial light modulator with transparent Schottky contact based on excitonic EA, which makes it possible to shift the absorption peak longer wavelength over 13 nm and produce more highly efficient modulator.

## 2. Device structure and experimental method

The structure of the sample used in our experiments for the study of voltage dependent absorption edge is shown in the Fig. 1. The sample consists of 5 μm thick HP i-GaAs epi-layer on (100)-oriented 20 μm thick $n^+$-GaAs substrate sandwiched between the Ohmic contact with a small window formed on $n^+$-GaAs substrate and the transparent Schottky contact (TSC) on i-GaAs. The transparent Schottky contact (TSC) were formed by coating two layers of an organic polyaniline (PANI) on i-GaAs by using spin coater (Mikasa 1HDX) [7]. Finally, the sample was fixed on the glass coated with Au/Ge/Ni with a small window similar to back contact of the sample in order to transmit an incident light by using “Araldite” thermosetting epoxy resin. A GaAs epilayers are grown by LPE method which is similar to that reported elsewhere [5]. Prior to deposition Ohmic contact and spin coating of transparent Schottky contact, both surfaces of the sample were cleaned by solvent and rinsed with de-ionized (DI) water, and the removal of an oxidation layer by a diluted acid solution was preformed.

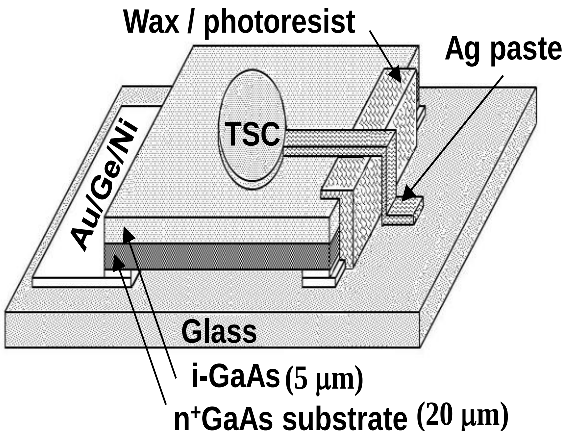


Fig. 1 A schematic diagram of a sample for voltage dependent optical transmission measurement.

The electric-field dependent optical transmission of the sample was measured at RT using a halogen light source and an optical spectrum analyzer (AQ6317B). The emitted light was coupled to a standard multimode fiber (MMF) and launched perpendicularly to epi-layer surface. Then, the transmitted light was coupled to a standard single mode fiber and detected by an optical spectrum analyzer. Both fibers were mounted on the x-y-z manipulators. The ends of both fibers were semi-spherically shaped to improve the coupling efficiency between the sample and fibers.

## 3. Result and discussion

Transmitted light intensity as a function of wavelength at different electric field magnitude at RT is shown in Fig.2, where the light is transmitted perpendicular to the junction. Figure 2 demonstrates excitonic EA effect at different electric field, although the bias magnitude is relatively large due to highly residual impurity (~$1\times10^{14}$ $cm^{-3}$). It is surprising that the excitonic absorption peak shifts to longer wavelength over 13 nm, whereas the oscillator strength does not decrease. The extinction ratio of 13.5 dB were observed at electric field of 70 kV/cm. Usually 3D exciton has weak binding energy compared with that of 2D and is assumed to be broadened with relatively small electric field intensity.

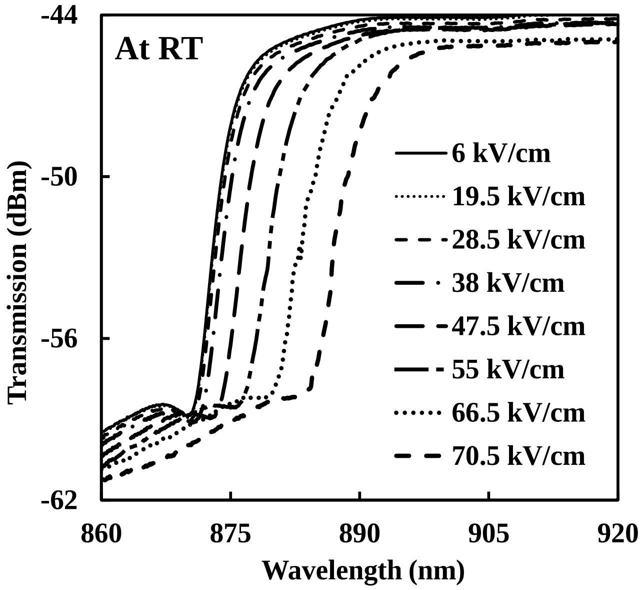


Fig. 2 Transmission vs wavelength as a function of electric field measured at the room temperature.

On the other hand, the excitonic absorption in the high-purity layer is stable even under high electric field intensity. Many reports on the excitonic absorption have been reported at low ambient temperature operation and no comments were given on the purity. Based on this experimental results, ultra-highly efficient modulator will be established when high purity epi-layers are used. The sample used in the present experiment is of relatively low purity (the carrier concentration is estimated to be $1\times10^{14}$ $cm^{-3}$). The thickness of epilayer is estimated to be around 5 μm from a clear Fabry-Perot interference mode observed over 880 nm wavelengths.

Figure 3 shows the relationship between the red-shift energy vs. applied electric field magnitude at RT. As far as the obtained experimental results are concerned, no clear decrease in oscillator strength is observed. Only small energy shift is observed upto 20 kV/cm and then abrupt energy shift starts from 40 kV/cm. This is due to poor depletion width. The energy shift is estimated to be 20 meV (13 nm ) at 70 kV/cm.

The large excitonic absorption peak shifts to longer

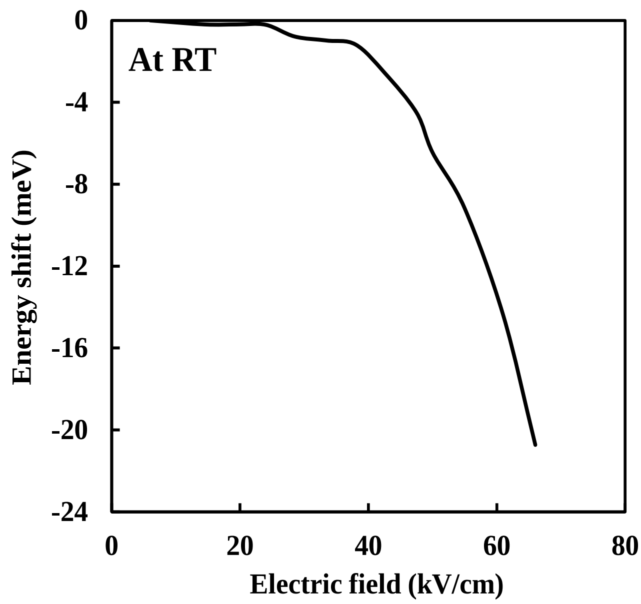


Fig. 3 Energy shift vs electric field

wavelength over 13 nm with low broadening, may be due to the high purity of the epitaxial layer. Broadening of exciton absorption peak is related to the carrier lifetime as well as ionization field. Carrier lifetimes in high-purity LPE grown GaAs have been reported exceeding 40 μs, although bulk GaAs are generally reported to be on the order of $10^{-8}$ s [8]. The excitons are not field ionized even when the electron and hole~~s~~ are pulled to opposite sides, because of a strong Coulomb attraction.

## 4. Conclusions

In conclusion, we believe that this is the first report demonstrating the shift of exciton resonance to longer wavelengths with low broadening measured at RT. This may be due to the high purity of the epitaxial layer. This is evidence that LPE grown layers are purer and has a potential for use of high-speed optical signal processing.

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