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Linear and nonlinear femtosecond pulse propagation through a quantum nano-structure optical waveguide observed with XFROG spectroscopy

Noriaki Tsurumachi[1,2], Naoki Watanabe[3], Kazunori Hikosaka[1,2], Xue-Lun Wang[1,2], Kazuhiro Komori[1,2], Toshiaki Hattori [3], and Mutsuo Ogura[1,2]

[1]National Institute of Advanced Industrial Science and Technology (AIST), 1-1-4 Umezono, Tsukuba, Ibaraki, Japan
[2]CREST–Japan Science and Technology Corporation (JST)
[3] Institute of Applied Physics, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Japan
Phone:+81-29-861-9237 Fax:+81-29-861-3389 E-mail: n-tsurumachi@aist.go.jp

1. Introduction

Semiconductor optical waveguides with quantum wells (QW), quantum wires (QWR) or quantum dots (QD) as an active material are important components for ultrafast photonic devices such as laser diodes, semiconductor optical amplifiers, and photonic switches. Knowledge of their properties on the transmission of ultrashort optical pulses is essential for the optimum design of these devices. However, distortion of optical pulses transmitted through them is very complicated, because both the amplitude and phase are changed by numerous linear optical factors such as refractive index dispersion, absorption or gain, and nonlinear optical effects such as two-photon absorption or self phase modulation.

Therefore, transmission properties of the optical waveguide in both time and frequency domains should be fully characterized first for the design of future photonic devices. In this paper, the transmission properties of a QW waveguide including polarization anisotropy in linear regime and nonlinear pulse propagation in a QW waveguide are investigated by XFROG spectroscopy.

Recently, frequency resolved optical gating (FROG) is often applied to full characterization of ultrashort optical pulses, since it gives us information of both amplitude and phase of the pulse field [1]. Although second harmonic generation FROG (SHG-FROG) is one of the most widely used methods of ultrashort pulse characterization, it often fails to retrieve a weak pulse. Cross-correlation FROG (XFROG) is more suitable for weak pulse characterization than SHG-FROG because this technique is based on the sum-frequency signal between a weak test pulse and a strong gate pulse [2]. Since the amplitude and the phase of the pulse in the time domain can easily be transformed to the amplitude and the phase information in the frequency domain, this XFROG technique can be applied to the measurement of the complex transmission coefficient of the sample in the linear regime. Not only the complex transmission coefficient in the frequency domain, but also the deformation of the ultrashort pulse in the time domain can be observed directly at the same time in both the linear region and the nonlinear region by the XFROG spectroscopy.

2. Experimental Procedure

In order to ensure high signal to noise ratio for optical communication, background-free measurement is desirable. Here we performed two kinds of background-free XFROG measurements. One is a two-color sum-frequency generation configuration. The combination of a Ti:sapphire laser and an optical parametric oscillator (OPO) provide a background-free measurement because the wavelength of the sum-frequency signal and the SHG signal from each pulses are different [3]. The other is a one-color type-2 SHG configuration. In this configuration, the SHG signal from each pulse is not generated, but only the cross-correlation signals are observed [4].

The laser system we used was based on a mode-locked Ti:sapphire laser and an OPO. The output from the Ti:sapphire laser, whose wavelength and pulse duration were around 800 nm and about 100 fs, respectively, was focused onto the waveguide facet by a microscope objective with a magnitude of 20 after chirp compensation using a prism pair. The spot diameter of the incident laser at the waveguide facet was about 5 μm. A part of the Ti:sapphire laser output was used to pump the OPO. The transmitted pulse and the gate pulse from the OPO, whose wavelength and pulse duration were around 1550 nm and about 150 fs, was overlapped on a BBO crystal and sum-frequency light was generated. The sum-frequency light spectra were recorded with a liquid N_2 cooled CCD camera as a function of the delay between the transmitted pulse and the gate pulse. We refer to them as XFROG traces. By retrieving the phase from an experimentally obtained XFROG trace, we obtained both the amplitude and phase of the pulse. We applied the XFROG spectroscopy to a semiconductor optical waveguide with GaAs/AlGaAs QWs.

3. Results and Discussions

Figure 1 shows the experimentally obtained XFROG trace for (a) the output pulse from the waveguide when the input is polarized perpendicular to the QW layer (TM polarization), and (b) the output when the input is polarized parallel to the QW layer (TE polarization) in a near resonant experiment at 10 K. Here, we performed the two-color XFROG spectroscopy. For the TM polarization, the XFROG trace obtained is tilted. This means that the longer wavelength

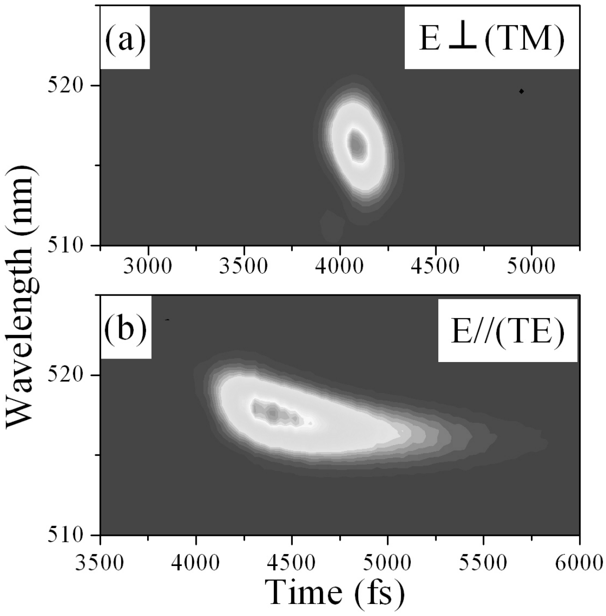

Fig.1

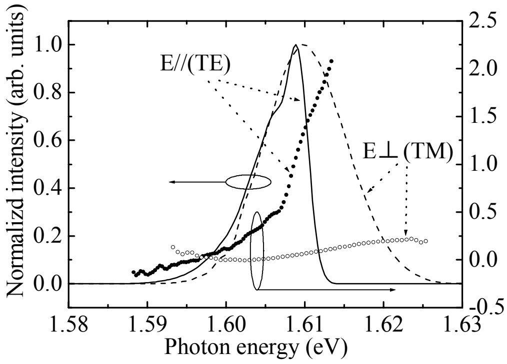

Fig.2

components travel faster than the shorter wavelength components. In contrast, with TE polarization, the XFROG trace has a very long tail. Figure 2 shows the retrieved transmitted intensity and group delay dispersion in the frequency domain. With TE polarization, the transmitted intensity of the higher energy side is greatly reduced and the group delay dispersion bends more than that of TM polarization. These differences between TE and TM polarization are attributed to the absorption anisotropy of QW. With TE polarization, QWs have both heavy hole (hh) and light hole (lh) exciton absorption. In contrast, with TM polarization, the hh exciton absorption is forbidden by the polarization selection rule and only the lh exciton absorption can be observed [5]. Therefore, the TE polarization light was influenced by the absorption and dispersion more than the TM polarization light.

Figure 3 shows the experimentally obtained XFROG trace for the output when the input intensity is (a) I_0 (=5.7μW/cm^2), and (b) 100 x I_0 at an off resonant experiment at room temperature. Here, we performed the type-2 SHG configuration XFROG spectroscopy. For the low intensity case, the XFROG trace is tilted due to the

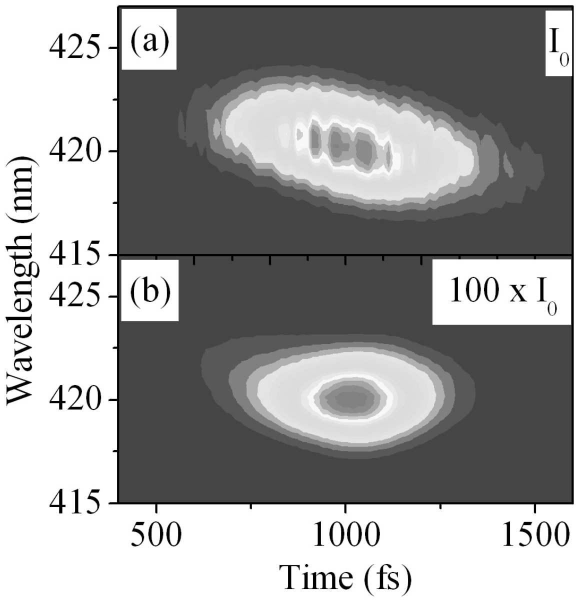

Fig.3

linear chirp. As the intensity increases, the inclination angle become smaller and both the temporal and spectral fields are become narrower. These behaviors can be interpreted as a soliton like propagation in an AlGaAs waveguide [6].

4. Conclusions

In summary, we investigated the femtosecond pulse propagation effects in a semiconductor QW waveguide by the XFROG spectroscopy. In a near resonance experiment of the QW waveguide, the polarization anisotropy of the QW was clearly observed in terms of the absorption and the dispersion. In an off resonance experiment, soliton-like nonlinear propagation was observed. The XFROG spectroscopy was shown to be a very simple and valuable technique for the characterization of waveguide type semiconductor photonic devices, since not only the linear but also the nonlinear complex transmission properties can be easily obtained using this technique.

References

[1] R. Trebino, K. W. Delong, D. N. Fittinghoff, J. N. Sweetser, M. A. Krumbügel, B. A. Richman, and D. J. Kane, Rev. Sci. Instrum. **68**, 3277 (1997).

[2]S. Linden, H. Giessen, and J. Kuhl, Phys. Stat. Sol. (b) **206**, 119 (1998).

[3]S. Haacke, R. A. Taylor, I. Bar-Joseph, M. J. S. P. Brasil, M. Hartig, and B. Deveaud, J. Opt. Soc. Am. B **15**, 1410 (1998).

[4]E.Abraham, E. Bordenave, N. Tsurumachi, A. Mito, G. Jonusauskas, J. Oberle, and C. Rulliere
Opt. Lett., **25,** 929 (2000).

[5]J. S. Weiner, D. S. Chemla, D. A. B. Miller, A. C. Gossard, W. Wiegmann, and C. A. Burrus, Appl. Phys. Lett. **47**, 664 (1985).

[6]N. Bélanger, A. Villeneuve, and J. S. Aitchison, J. Opt. Soc. Am. B **14**, 3003 (1997).