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Measurement of Carrier Lifetime in Microcrystalline Silicon for Optical Modulator

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***Abstract*:** We measured a carrier lifetime of microcrystalline silicon for the purpose of application to an optical modulator. The lifetime was measured by the pump-probe method. The measured carrier lifetime was in the range of 3 ns to 25 ns depending on the temporal width of pump pulse.

1. Introduction

Microcrystalline silicon (μc-Si:H) is composite material consisting of nanometer-sized crystallite and amorphous silicon (a-Si:H) domain. μc-Si:H can be grown at low temperatures by plasma enhanced chemical vapor deposition (PECVD), as is grown in the same fashion as a-Si:H but with different deposition conditions [1, 2]. We proposed an a-Si:H optical modulator in order to utilize its ultrafast carrier relaxation for high-speed optical modulator [3], but μc-Si:H is superior to a-Si:H in terms of improved dopant activation efficiency and mobility while keeping advantages of a-Si:H such as low temperature and low cost fabrication, making it compatible with the back-end process of complementary metal-oxide-semiconductor.

Optical modulators are indispensable in optical communication systems. Downsizing and cost reduction of optical modulators are needed especially for short-reach communication applications. When a carrier plasma effect is used in the optical modulator, a carrier lifetime becomes critical for the response speed.

In this paper, we measure carrier lifetime of μc-Si:H waveguide by pump and probe method to test the feasibility of μc-Si:H for its application to a high speed optical modulator in a 1.55 μm telecommunication wavelength range.

2. Experimental Setup

Carrier lifetime was measured by a pump-probe method based on the cross amplitude modulation. The intensity of continuous wave (CW) probe light is modulated due to the optical nonlinear effect caused by an intense pump light pulse simultaneously launched to a waveguide. When the intense pump light is propagated in the waveguide, free carriers are excited by two-photon absorption. This causes free carrier absorption, which results in the attenuation of the probe light intensity. In this process, the recovery of the modulated probe light intensity corresponds to the disappearance of the excited carriers. Therefore, the lifetime of the free carrier excited in the waveguide can be measured by measuring the rise time of attenuated probe light intensity.

A waveguide is formed by etching the μc-Si:H layer, deposited on SiO_2 by PECVD process, using a SF_6 reactive ion etching technique. The height and width of the waveguide is 220 nm and 500 nm, respectively. Tapered spot size converters are installed at the input and the output end of the waveguide in order to improve the light coupling efficiency as shown in Fig. 1. The total length of waveguide is 4500 μm including 200 μm long tapers on both ends.

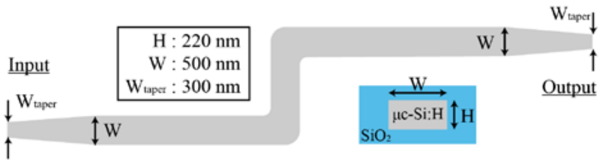

Fig. 1. Structure of waveguide.

The measurement was carried out using a fiber-device-fiber setup shown in Fig. 2. Different telecom wavelengths were used to distinguish the probe light from the pump light. The pump light pulse was generated by modulating a CW light of 1530-nm wavelength in a lithium-niobate optical modulator with an electrical signal fed by a pattern generator (PPG) with a clock signal provided by an arbitrary signal generator (ASG). The pump pulse was amplified up to an averaged power of 25 dBm by an erbium-doped fiber amplifier (EDFA). A CW light of 1560-nm wavelength generated by a tunable laser diode (TLD) set was used as probe light, which was amplified to about 16 dBm by another EDFA. Both pump and probe lights were polarized to the TM mode by using polarization controllers (Pol Cntr) after passing through optical isolators. The polarized pump and probe light were combined in a 3-dB coupler. An output of the 3-dB coupler was coupled to the waveguide using a lens-tipped optical fiber. The other light output was used to monitor the power of light through a 20-dB attenuator (Attn). The temporal response of the transmitted probe output from the waveguide was measured by using an avalanche photodiode (APD) and an oscilloscope (OS) after passing through a band-pass filter (BPF) for eliminating the pump light.

PPG was operated in 20 GHz with a minimum pulse width of 50 ps. The pulse width was controlled by the number of sequential bits in PPG. In this experiment, the repetition period of pulses was set to 1000 ns (20000 bits).

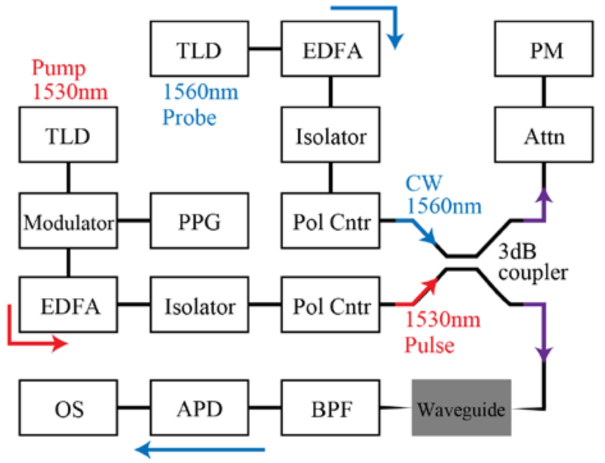

Fig. 2. Schematic of pump-probe setup.

3. Measurement Result

The temporal response of the probe light was measured for varying the width of pump pulse in the range of 0.1 ns to 50 ns. The measurement results are shown in Fig. 3, where the probe light waveform rising from the attenuated level is shown. The attenuated level depends on the pump pulse width. In this figure, the waveform is normalized so as to have a constant decrease in amplitude for various pulse widths, which enables us to directly compare the temporal response. The probe responses are plotted in Fig. 3 for pump pulse widths of 1, 5, 10, 30 and 50 ns.

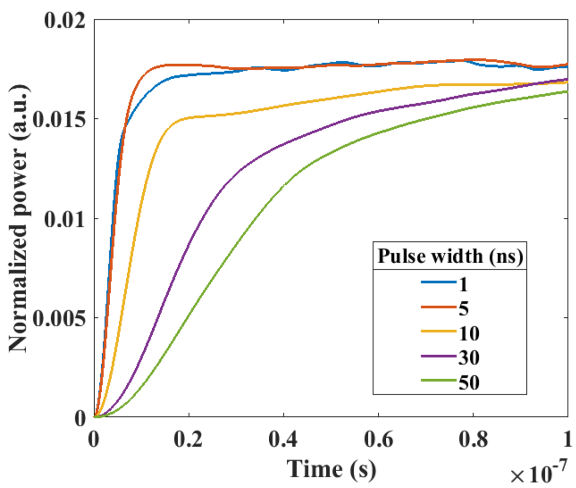

Fig. 3. Rising waveform of probe output.

It is clearly observed that the rising time needed to recover the output level increases as the pump pulse width becomes larger. We analyzed the measured waveform to estimate the carrier lifetime. Several relaxation processes can contribute to the recovery of the probe light output from an attenuated level. We interpolated the measured rising response with two exponential functions having different lifetimes. The faster contribution is plotted in Fig. 4 as a function of pump pulse width.

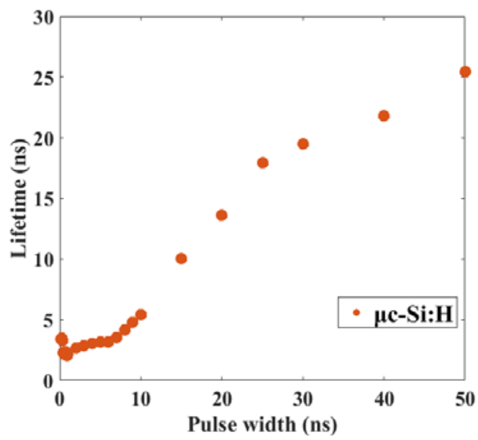

Fig. 4. Measured carrier lifetime of μc-Si:H as a function of pulse width.

4. Conclusion

The carrier lifetime of μc-Si:H was measured by using a pump-probe method. The pulse width of the pump light was varied from 0.1 ns to 50 ns. Measured carrier lifetime varied from 3 ns to 25 ns with a monotonic increase according to the increase in pump pulse width. It is necessary to measure the two-photon absorption coefficient to estimate the excited carrier density from measurement results. We then design and discuss an optical modulator of carrier injection-type or depletion-type, which could be better. In addition, we explore a faster lifetime of μc-Si:H by considering dynamics of carrier relaxation in the complex band structure.

References

[1] A. Matsuda, "Formation kinetics and control of microcrystallite in μc-Si:H from glow discharge plasma," Journal of Non-Crystalline Solids **59-60**, 767-774 (1983).

[2] T. Kamei, et al., "A Significant Reduction of Impurity Contents in Hydrogenated Microcrystalline Silicon Films for Increased Grain Size and Reduced Defect Density," Jpn. J. Appl. Phys., **37**, 265–268 (1998).

[3] R. Takei, et al., "Carrier injection refractive index changes in low-temperature grown silicon waveguide," GFP2014, 239–240 (2014).