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Second harmonic generation of pseudo mode-locked multi ten milliwatt picosecond Ti:sapphire laser

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Abstract

We report the single-pass second harmonic generation (SHG) of the picosecond Ti:sapphire laser with a periodically poled lithium niobate (PPLN) waveguide. We demonstrate a conversion efficiency of 37% for the 9-mW fundamental input power at 820 nm. This laser source can provide three types of pulsed modes such as picosecond, nanosecond, and contiuous wave, by adjusting the power of the pumping source. We compare the conversion efficiency in each mode, and clearly show that SHG efficiency depends on the pulsewidth, that is, the peak power of the laser source. As the temperature of the PPLN rises, the fundamental wavelength for phase-matching becomes longer. We indicate that the rate is about 0.06 nm/K.

Keywords: Picosecond; Ti:sapphire laser; SHG; PPLN

1. Introduction

The pump-probe measurement using an ultrashort pulse laser is one of the powerful methods in the research fields of various ultrafast phenomena [5], and Ti:sapphire laser is often used as a light source. We have developed a light source for pump-probe measurements with such a narrow linewidth that can be applied to subjects, which involve a narrow absorption region. The Ti:sapphire laser with an acoustic optic tunable filter in the resonator operates in a pseudo mode-locked mode with a pulsewidth of 10 ps and a linewidth of 100 pm. The laser frequency can be tuned by a fast electronic control system. Although this source can cover the wavelength region of 740–860 nm, it is very important to broaden the spectral region by frequency conversion such as second harmonic generation (SHG). Thus, we aimed at obtaining picosecond second harmonic light with the highest possible efficiency. Since, the narrow linewidth of this source is achieved at the sacrifice of peak power, high conversion efficiency is not expected with bulk nonlinear crystal. Instead, we adopted waveguide-type quasi-phase-matching-SHG (QPM-SHG) crystal which gives high conversion efficiency for low input power by single-pass transmission.

In order to realize an efficient device with second-order nonlinear optical (NLO) effects, such as SHG, it is necessary to obtain phase-matching within a material with high nonlinearity. A QPM device has a structure, which reversed (or modulated) the sign of NLO coefficient with a period Λ along the propagation axis, and is the method of taking phase-matching by compensating with the wave vector $\boldsymbol{K}$ ($|\boldsymbol{K}|=K=2\pi/\Lambda$) of the wave which is going to generate NLO polarization. NLO interaction is analyzable with nonlinear coupled-motion equation [1,2]. Since, QPM can be applied to arbitrary wavelength combination, a device for wavelength conversion in a very large wavelength range is realizable with a single material. In the case of SHG, the harmonic power $P_0^2\kappa_{\mathrm{SHG}}^2L^2$ increases

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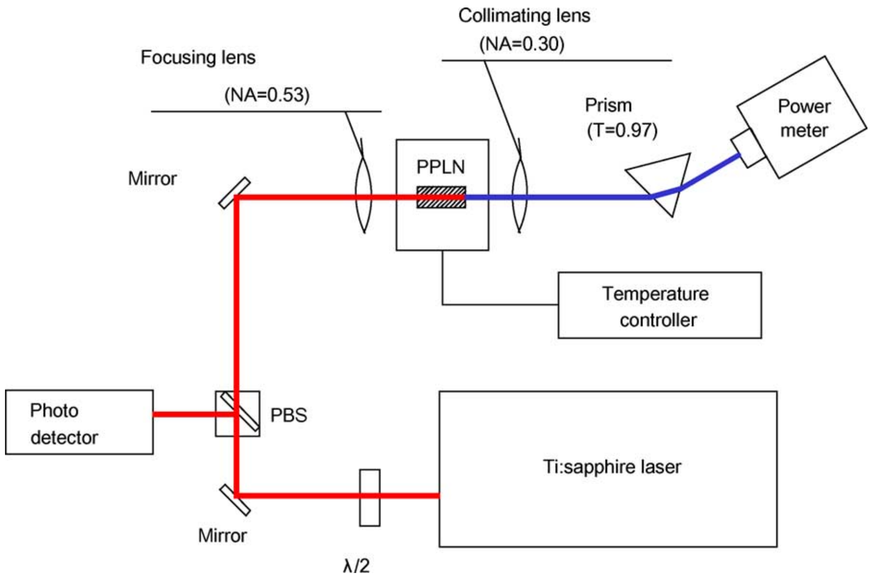

Fig. 1. Schematic of the experimental set-up.

monotonically with fundamental input power P_0 and interaction length L in the limit of low input power, where κ_{SHG} is the coupling coefficient.

Researches and developments regarding periodically poled lithium niobate (PPLN) are most advanced and have been reported mostly for QPM device [3]. We adopt a PPLN crystal and investigate the conversion efficiency for three laser modes [6–8] namely picosecond, nanosecond, and contiuous wave (cw) by adjusting the power of the source. When the temperature of the PPLN is higher, pitches of the periodically poling become wider. As a result, the fundamental wavelength for phase-matching becomes long.

2. Experimental

Experimental system is shown in Fig. 1. The light from the Ti:sapphire laser source was arbitrarily attenuated in the combination of the half wave plate and the polarization beam splitter (PBS), and coupled to the input end of PPLN crystal with the object lens (NA = 0.53). The generated second harmonic light was collimated by another object lens (NA = 0.30), separated by the prism (transmission is about 0.97) with fundamental light, and measured by the optical power meter. The light separated by PBS is measured with a photo detector and oscillation mode is observed on real time (Fig. 2). The peak power of the pulse P_P can be found from

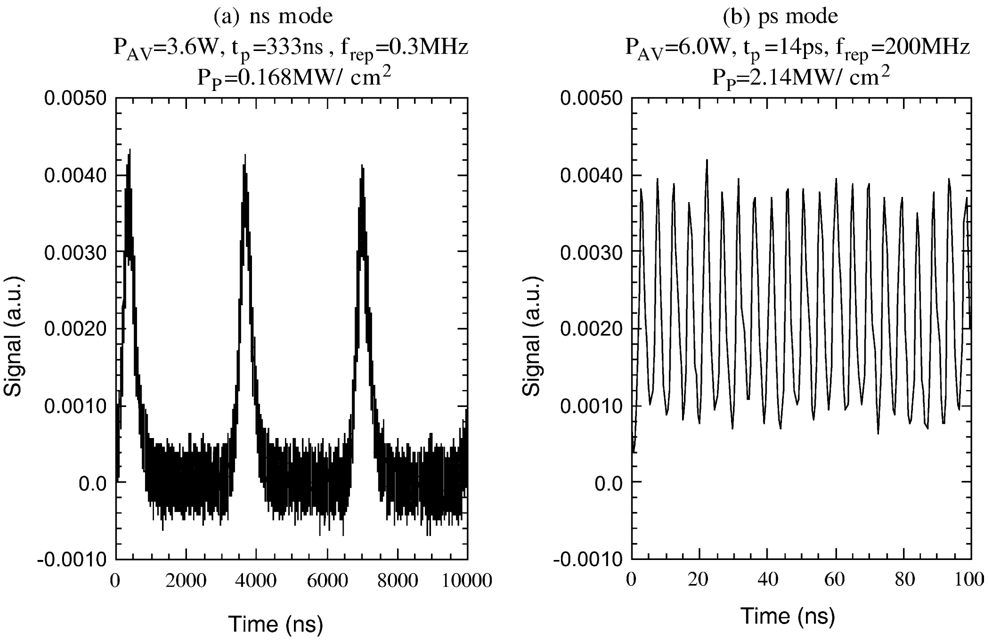

Fig. 2. Temporal intensity profile at (a) ns and (b) ps modes.

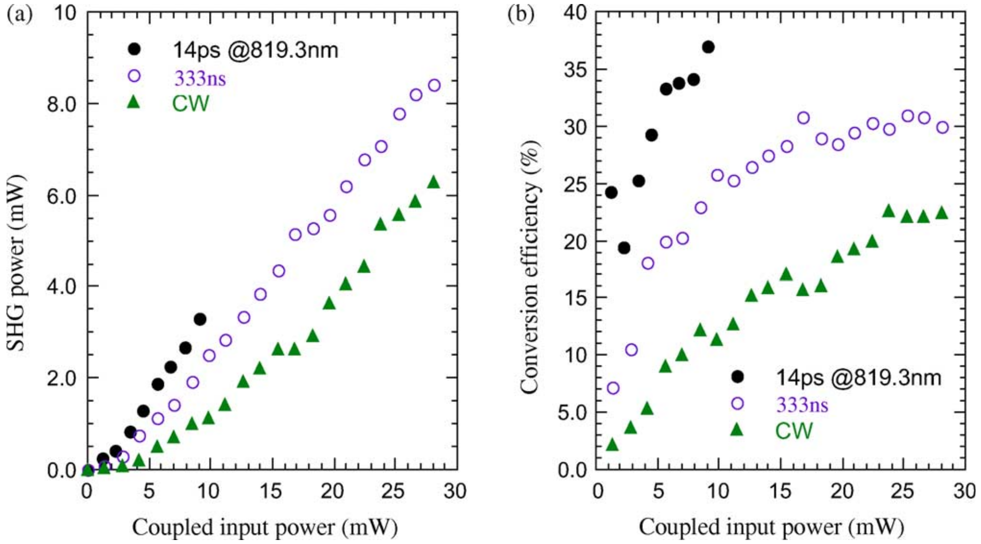

Fig. 3. (a) SHG power and (b) conversion efficiency vs coupled input power at a fundamental wavelength of 820 nm.

pulse width t_p and period $T(=1/f_{rep})$ of the pulse that is obtained from Fig. 2 and average power of the light P_{AV} $P_P=P_{AV}f_{rep}/t_p$. Although accurate comparison cannot be performed because of a limit of the time resolution of the photodetector at picosecond mode, the peak power at picosend mode is 10 or more times higher than that at nanosecond mode (Fig. 2).

The length and periodically poling pitch of PPLN crystal at 820 nm fundamental is 8.5 mm and 2.8 μm, and edges of the crystal are optically polished. This crystal has a resistance against to photorefractive effect with MgO doping [4], and is under control of temperature (Fig. 1).

3. Results and discussion

Fig. 3(a) shows second harmonic power vs coupled input power at a fundamental wavelength of 820 nm at room temperature. The second harmonic is separated from the fundamental light by a prism. We find that output power is highest in the picosecond (14 ps) mode and lowest in the cw mode. This indicates that higher output power is obtained for higher peak power of the input pulse. Fig. 3(b) shows the conversion efficiency calculated directly from Fig. 3(a). The highest conversion efficiency was 23% in cw mode at input power over 24 mW, 30% in 333-ns mode at input power over 17 mW, and 37% in 14-ps mode at input power of 9 mW. Although we have not tried higher input power to avoid photorefractive damage at 14-ps mode, higher conversion efficiency would be demonstrated for higher input power. Conversion efficiency saturates at high input power due to propagation loss of the second harmonic. Similar experiments were performed at a fundamental wavelength of 757 nm, and conversion efficiency was 17% in 14-ps mode, which is lower than value for 820 nm, since the SH wavelength approaches the absorption region of lithium niobate (about 300 nm).

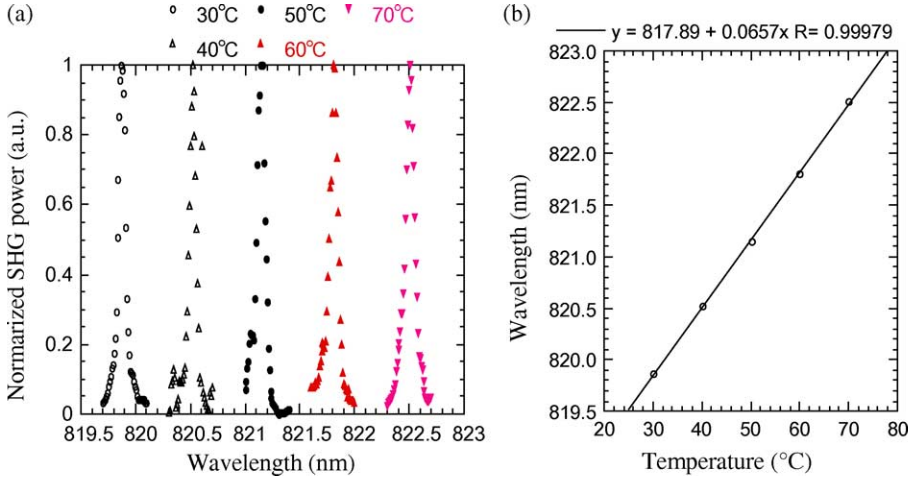

Fig. 4. (a) Normalized SHG power spectrum at different values of PPLN temperature. (b) The peak fundamental wavelength as a function of PPLN temperature.

Fig. 4(a) shows normalized second harmonic power spectrum for different PPLN crystal temperatures. Fig. 4(b) plots the peak fundamental wavelength as a function of PPLN temperature. The relation is approximately linear, and the fundamental wavelength goes up by 0.0657 nm/K.

The conversion efficiency of 37% demonstrated in 14-ps mode at 9 mW input power is very high, and even higher efficiency would be achieved by the optimization of the interaction length and the crystallinity of the PPLN waveguide. Thus, PPLN crystal is suitable for obtaining ultraviolet coherent light at low input power.

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