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A compact light source at 399 nm using a periodically poled $LiNbO_3$ waveguide for laser cooling ytterbium

Takumi Kobayashi(1), Daisuke Akamatsu(1), Yoshiki Nishida(2), Takehiko Tanabe(1), Masami Yasuda(1), Feng-Lei Hong(1)(3), and Kazumoto Hosaka(1)
(1) National Metrology Institute of Japan (NMIJ), National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Umezono, Tsukuba, Ibaraki 305-8563, Japan
(2) NTT Electronics Corporation, 6700-2 To, Naka-shi, Ibaraki 311-0122, Japan
(3) Department of Physics, Graduate School of Engineering, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan

1 Introduction

Cold ytterbium (Yb) atoms have attracted considerable attention in various research fields, including development of optical lattice clocks [1], quantum simulation [2], and quantum information processing [3]. In experiments with cold Yb atoms, high power light sources at 399 nm resonant on the ${}^1S_0 - {}^1P_1$ transition have been used to cool atoms to a temperature of several millikelvin. A compact and robust 399-nm light source is useful for such experiments. Some groups have developed blue external cavity diode lasers (ECDL) emitting at 399 nm. To generate sufficient power for cooling Yb atoms, an injection locked 399-nm diode laser has been employed to amplify the output power from an ECDL at 399 nm. Another method to generate a 399-nm light is second harmonic generation (SHG) of a 798-nm ECLD. A nonlinear optical crystal, e.g., a lithium triborate (LBO) or barium borate (BBO), has conventionally been placed in a power-buildup cavity to obtain a high SHG power. The output power at 399 nm using this SHG method is typically higher than that of the blue diode laser system. However, this SHG scheme requires the locking of a high-finesse cavity, which compromises the compactness and robustness of a laser system.

In the present work, we report a compact light source at 399 nm using a single-pass periodically-poled $LiNbO_3$ (PPLN) waveguide for the SHG [4]. High conversion efficiency in a single-pass configuration can be obtained with a PPLN waveguide, since its waveguide structure allows a confined beam to travel in a PPLN crystal. A PPLN waveguide is therefore attractive for developing a compact and robust laser system. In the present setup, the generated SHG light was amplified by injection locking. We successfully carried out laser cooling of Yb atoms using our light source.

2 PPLN waveguide

The PPLN waveguide was manufactured by NTT Electronics Corp. We fabricated a 11.6 μm-wide and 22 mm-long waveguide with a periodically poling period of 7.625 μm to realize 3rd-order quasi-phase mathching. Figure 1 shows the measured SHG power as a function of the fundamental power P_{in} which is coupled to the PPLN waveguide. A maximum power of 25 mW was obtained at 399 nm when $P_{in} = 380$ mW. We observed a reduction of the SHG power for $P_{in} > 380$ mW. This is due to the fact that the generated 399-nm light is absorbed in the PPLN. The SHG power was stable day after day for several months when we used the PPLN waveguide with $P_{in} < 200$ mW.

3 Light source at 399 nm for laser cooling Yb atoms

For laser cooling Yb atoms, we developed a compact light source at 399 nm consisting of a 798-nm ECDL with a tapered amplifier (TA) as a fundamental input laser, the PPLN waveguide, and a slave diode laser for injection locking. The setup of the salve laser was similar to that of Ref. [5]. The laser system generated an output power of 200 mW at 399 nm when a seed power of 2 mW was injected into the slave laser. Figure 2 shows a picture of the 399-nm system developed on two breadboards with areas of 45 cm $\times$ 45 cm that can be installed in a 19-inch rack. One advantage of our laser system compared with an injection locked 399-nm slave diode laser using another blue ECDL is the utilization of a 798-nm diode laser which has good longitudinal and transverse modes. Another advantage is that the 798-nm ECDL can easily be linked to an optical frequency comb based on a mode-locked erbium-doped fiber laser ($1000-2050$ nm) or a titanium sapphire laser ($500-1100$ nm). Our 798-nm ECDL was stabilized to a fiber-based frequency comb by detecting a beat note between the 798-nm light and an SHG comb component.

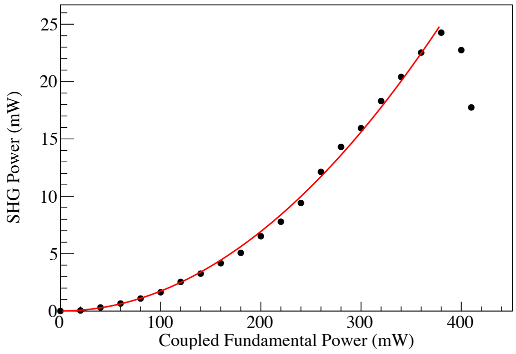

Figure 1. SHG power as a function of the fundamental power which is coupled to the PPLN waveguide. The solid red curve shows the best fit of a quadratic function.

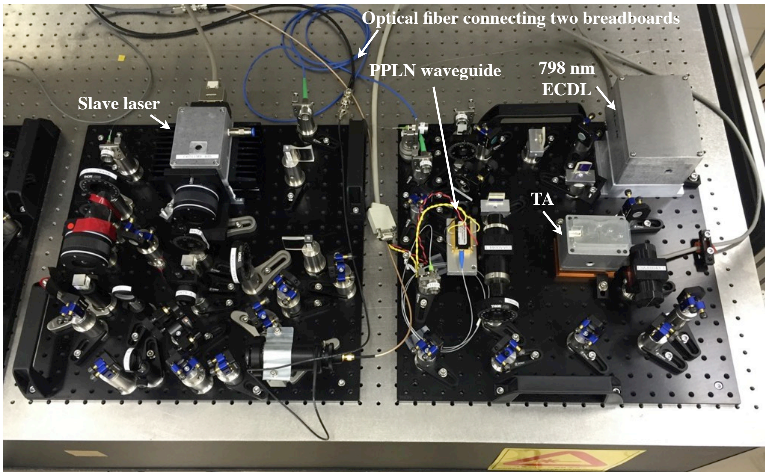

Figure 2. Picture of our compact light source for laser cooling Yb atoms.

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