DIODE-LASER-BASED LIGHT SOURCES FOR LASER COOLING OF TRAPPED Yb^+ IONS

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Abstracts

We are developing a light source at 370 nm for driving of the $^2S_{1/2}$ – $^2P_{1/2}$ cooling transition by sum-frequency mixing of radiation from two diode lasers with a doubly resonant external cavity. To drive the $^2D_{3/2}$ – $^3D[3/2]_{1/2}$ repumping transition at 935 nm, we developed two types of external cavity diode lasers. Applications of them to laser-cooled trapped Yb^+ ions are also presented.

Introduction

Singly ionized ytterbium ion (Yb^+) is one of the potential candidates which provide frequency references in future frequency standards from microwave to optical region [1-5]. All-solid-state laser systems, in particular based on diode lasers, are attractive to realize compact experimental systems, and a long-time operation required for investigation of the performance as frequency standards.

So for, all-solid-state light sources for laser cooling of Yb^+ ions have been realized by Tamm and Engelke [6]. They have developed a light source at 370 nm by second harmonic generation (SHG) of a low power diode laser at 740 nm with a high-finesse external cavity, and a diode-laser pumped fiber laser at 935 nm. For radiation at 935 nm, use of diode lasers is an alternative solution [3,4].

In this presentation, we report our diode-laser based light sources for laser cooling of Yb^+ ions, and their applications to laser-cooled trapped Yb^+ ions. In particular, as an alternative approach for radiation at 370 nm, we are developing sum-frequency mixing (SFM) of radiation from two diode lasers at 671 nm and 822 nm, because the from commercially-available diode lasers at these wavelengths have higher powers than that at 740 nm. And also, for 822 nm, we can use the radiation frequency-stabilized for high resolution spectroscopy of the $^2S_{1/2}$ – $^2D_{5/2}$ transitions in Yb^+ or the 6S-8S two-photon transitions in Cs [7].

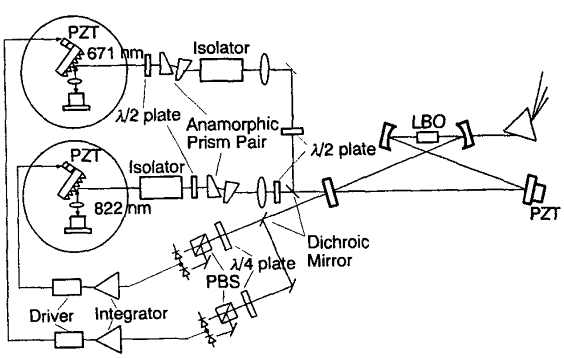

Fig. 1 Experimental set up of sum-frequency mixing.

Result

A light source at 370 nm. Figure 1 shows a schematic of the light source at 370 nm. We constructed a doubly resonant external cavity to enhance the conversion efficiency of SFM in a LBO crystal of a length of 10 mm. We prepared two external cavity diode lasers (ECDL). Fundamental enhancement factors were measured to be 12 and 26 for 671 nm and 822 nm, respectively. We obtained UV radiation of 30 μW from radiation of 8 mW and 41 mW at 671 nm and 822 nm, respectively, while the UV power expected by theoretical calculation was 35 μW. In the case of SFM, the output sum-frequency can be swept by changing the cavity length, while the frequencies of the two fundamental lasers are locked to the resonances of the cavity. Continuous frequency tuning of 3.5 GHz was obtained in the generated radiation at 370 nm by sweep of the voltage applied to a piezotransducer (PZT) controlling the cavity length.

Light sources at 935 nm. We have developed two types of ECDLs. One has a tapered-stripe tip as a gain media. This external cavity tapered diode laser (ECTDL) was constructed in a double-ended cavity configuration. The details of the ECTDL are described in elsewhere [8]. The other is an ordinary ECDL in the Littlow configuration. We controlled a rotation of the grating by three PZTs, and obtained a continuous tuning of 8 GHz at around the center wavelength at 941 nm of the diode-laser tip. It decreased to 4 GHz at 935 nm.

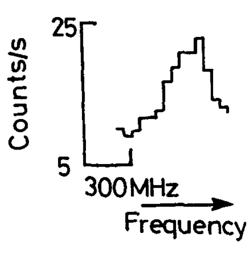

Fig. 2 Spectrum of laser cooled $^{174}Yb^+$ ions obtained by frequency sweep of radiation generated by the SFM. Gate time of each point was 10 s.

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Application to Yb^+ ions. We have been applying these light sources to laser-cooled trapped Yb^+ ions. We used a RF trap, the minimum inner diameter of the ring electrode of which was 5 mm. We used a natural isotope mixture of Yb as a source of ions. For help of the experiments of laser cooling, we used second-harmonics of radiation from a dye laser as radiation at 370 nm (SH radiation), and radiation at 935 nm from a Ti:Al_2O_3 laser (TiS radiation). We detected fluorescence of trapped Yb^+ ions by a photomultiplier [9,10]

Figure 2 shows a spectrum of laser-cooled trapped $^{174}Yb^+$ ions obtained by frequency sweep of radiation generated by the SFM. We also detected fluorescence of $^{171}Yb^+$ ions. $^{171}Yb^+$ is an important isotope because it has magnetic-field-insensitive transitions. We drove the cycling transition of the $^2S_{1/2}(F=1)$ – $^2P_{1/2}(F=0)$ by SH radiation. By driving the $^2S_{1/2}(F=0)$ – $^2P_{1/2}(F=1)$ transition with radiation generated by the SFM, we avoided optical pumping to the $^2S_{1/2}(F=0)$ state. TiS radiation was tuned to the $^2D_{3/2}(F=1)$ – $^3D[3/2]_{1/2}(F=0)$ transition [11].

We detected spectra of the $^2D_{3/2}$ – $^3D[3/2]_{1/2}$ transition at 935 nm in single $^{174}Yb^+$ ions by using the ECTDL. We measured the isotope shifts of this transition among four even isotopes by using the ECDL. In this measurement, we laser cooled small number of certain isotope of Yb^+ ions by using SH and TiS radiation. Then, we frequency swept the ECDL at 935 nm with blocking the TiS radiation. During the sweep, we switched the frequencies of the SH and TiS radiation to those for the next isotope. When we could not detect fluorescence of the next isotope of Yb^+, we produced it, before the ECDL tuned to its resonance.

The measured isotope shifts are -3.464(10) GHz (170 – 172), 2.612(3) GHz (174 – 172), and 5.074(19) GHz (176 – 172). From King plot between these values and those for the $^2S_{1/2}$ – $^2P_{1/2}$ transition measured by Martensson-Pendrill et al. [12], we determined that F_{935}/F_{370} = 2.501(27) and $K_{935} - K_{370}F_{935}/F_{370}$ = 8.72(56) THz u, where F_i is the electric field shift factor, and K_i is the mass shift factor. Subscripts 370 and 935 indicate the $^2S_{1/2}$ – $^2P_{1/2}$ and $^2D_{3/2}$ – $^3D[3/2]_{1/2}$ transition, respectively. From the values of F_{370} and $K^{SMS}{}_{370}$ calculated in [12], we derived F_{935} and $K^{SMS}{}_{935}$ to be –37.3(5) GHz fm^{-2} and 10.1(6) THz u, respectively, where K^{SMS} is the specific mass shift factor.

Conclusions

We have demonstrated the possibility of generating several tens of microwatts of radiation at 370 nm by sum-frequency mixing of radiation from two diode lasers with doubly resonant external cavity. We have developed two types of external cavity diode lasers at 935 nm. Using these light sources, we detected fluorescence of laser-cooled trapped $^{174}Yb^+$ and $^{171}Yb^+$ ions, and measured the isotope shifts of the $^2D_{3/2}$ – $^3D[3/2]_{1/2}$ transition at 935 nm.

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