Tuning of spectrally narrowed lasers by an electro-optic modulation technique

P-5-05

Nilesh J. VASA, Shigeru YOKOYAMA, Michihiro UCHIUMI*, Mitsuo MAEDA**

Interdisciplinary Graduate School of Engineering Sciences,
Kyushu University, Kasuga 816-8580, Japan
*Ariake National College of Technology, Omuta 836-8585, Japan
**Graduate School of ISEE, Kyushu University, Fukuoka 812-8581, Japan
E-mail: vasa@ence.kyushu-u.ac.jp

Abstract : A wavelength switching method for tuning a self-injection-seeded Ti^{3+}:sapphire laser is reported that uses an electro-optic beam deflection technique. This configuration can allow a simple tuning approach where fast and stable electronic wavelength switching is required in a narrow tuning range, between few tens of pm to nm order, without involving any mechanical movement.

Differential absorption lidar (DIAL) system in UV (ultra-violet) and near-infrared region is being widely used for remote sensing of ozone, SO_2, and H_2O vapor, respectively [1]. On the other hand, many gases and chemicals of interest have absorption lines in the mid-infrared (2 -4μm) wavelength region - examples include CO_2, CH_4, CO, NO_2, HCl and so on. The present research is aimed at developing a mid-infrared DIAL system for remote sensing of these greenhouse gases.

DIAL involves measurements made using a tunable pulsed laser at two different wavelengths which are sequentially or simultaneously transmitted over the same path in the atmosphere. One laser beam (ON-wavelength) is absorbed by the molecular species of interest and the other laser beam (OFF-wavelength) is not strongly absorbed. The measurements are based on molecular and Mie backscattering from the atmospheric aerosol and the analysis of the difference between the two temporal signals provides range-resolved measurements of the concentration of the absorbing molecule.

In the previous experiments, difficulties related to quick sequential changing of the ON- and OFF-wavelengths were encountered, and each measurement involved long time. Quick and reliable sequential changing of the ON- and OFF-wavelengths is necessary to avoid adverse effect of time dependent atmospheric fluctuations [2].

Here we report about a novel method of tuning of a spectrally narrowed Ti^{3+}:sapphire laser by employing a wavelength switching method that uses an electro-optic beam deflection technique. A spectrally narrowed Ti^{3+}:sapphire laser is obtained by using a dual-cavity type oscillator with a diffraction grating, which acts as a spectral narrowing element in the grazing incidence cavity, and in order to tune the spectrally narrowed output without any mechanical movement, an electro-optic $LiNbO_3$ prism is introduced in the tuning arm of the dual-cavity. When an external electric field is applied to the prism, the diffraction angle alters resulting in a beam deflection on the tuning mirror and the wavelength tuning is achieved without rotating the tuning mirror.

Figure 1 shows the experimental setup with a $LiNbO_3$ electro-optic prism located in the tuning arm of a Ti^{3+}:sapphire laser. Spectrally narrowed, tunable output with the self-injection-

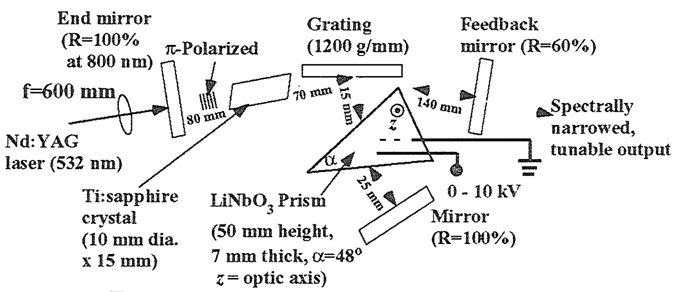

Figure 1: Experimental setup.

seeding was confirmed by using a monochromator (Nikon, G-500 III). The spectral characteristic of the laser was measured by using a Fabry-Perot interferometer (Burleigh, RC-140).

Figure 2 shows the interferograms of the Ti^{3+}:sapphire laser (at 785 nm) with and without the application of the electrical voltage to the $LiNbO_3$ prism. The interference fringe pattern

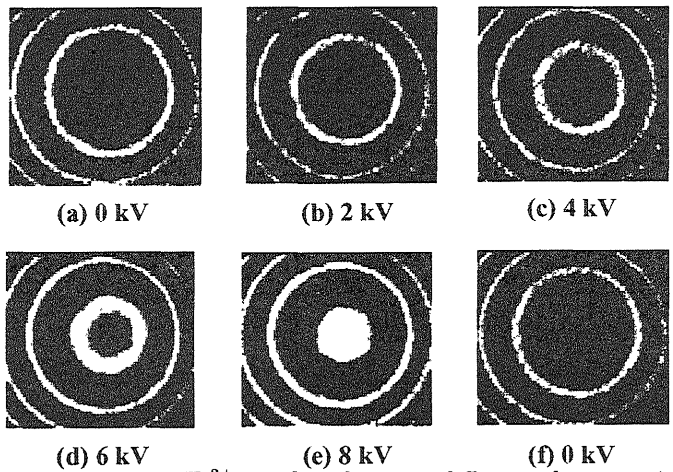

Figure 2: Fabry-Perot interferograms of Ti^{3+}:sapphire laser at different electro-optic voltages. (a) Without, (b to e) with the application of voltage to the prism, and (f) when the voltage is reduced to zero. Free spectral range = 1.66 cm^{-1} .

was altered with the change in the value of the voltage, which confirmed a narrow-band tuning by the electro-optic light-beam deflection method. When the electrical voltage was returned to the zero value, the fringe pattern shown in Fig. 2(f) was also returned to its initial pattern, similar to observed in in Fig. 2(a). The spectral widths of the self-injection-seeded Ti^{3+}:sapphire laser, with and without the application of the electrical voltage, were measured as $\approx$ 0.05 cm^{-1}.

Wavelength tuning of $\approx$94 pm was attained with an applied electric field of 10 kV/cm. The experimental results at different wavelengths were in close agreement with the theoretical estimation based on an electro-optic analysis [3]. When a Ti^{3+}:sapphire laser is used along with a Raman shifter for a CO_2-DIAL application, ON-OFF wavelength tuning of around 50 pm is necessary, and the experimental results clearly show that it can be achieved with the electro-optic beam deflection technique.

Alternative approaches can also be considered for producing larger change in the electro-optic beam deflection angle. These include: (1) using crystal having large electro-optic coefficients, (2) using multiple prisms, (3) applying uniform electric field to a domain inverted sample [4]. In the approach (2), the attainable deflection angle increases as a linear function of the number of prisms. Further, theoretical calculation also show that the deflection angle can be increased by a factor of two by applying a uniform electric field to a domain inverted prism set.

In summary, a novel wavelength switching method for a self-injection-seeded Ti^{3+}:sapphire laser is demonstrated that uses an electro-optic beam deflection technique. A LiNbO3 prism was used in the tuning arm of the laser and the tuning range of $\approx$94 pm was attained with an applied electric field of 10 kV/cm to the prism. The tunable range of the spectrally narrowed laser can be expanded to nm order with alternative geometries of the electro-optic beam deflector. Similar technique can also be employed for diode pumped Cr^{3+}:$LiSrAlF_6$ all-solid-state tunable lasers.

Reference

1) M. Uchiumi and M. Maeda: Rev. Laser Eng. **22** (1993) 448.

2) M. Uchiumi, N. J. Vasa, M. Fujiwra, S. Yokoyama, M. Maeda, and O. Uchino: SPIE (Lidar Remote Sensing for Industry and Environment Monitoring III) **4893** (2003) 141–149.

3) A. Yariv and P. Yeh: *Optical Waves in Crystals* (John Wiley and Sons, Inc., New York, 1984), Chap. 7.

4) R. W. Eason, A. J. Boyland, S. Mailis, and P. G. R. Smith: Opt. Commun. **197,** (2001) 201–207.