

DEVELOPMENT OF A SIMULTANEOUS MULTI-WAVELENGTH DYE LASER FOR DIFFERENTIAL ABSORPTION TECHNIQUE

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A compact and simple simultaneous multi-wavelength dye laser cavity was developed for a differential absorption technique. Dielectric multilayer interference filters were inserted inside the cavities as tuning elements, and two types of a DIAL system were constructed by using the dye laser tuned with dielectric multilayer filters to measure NO₂ concentration. The usefulness of this dye laser was clarified for the differential absorption technique in outdoor experiments.

Some basic designs of the laser cavity with these filters to get simultaneously multi-wavelength output are summarized in Fig.1. When a filter is set outside a cavity, the linewidth of the output spectrum of the dye laser becomes wider than that at the incident angle 0° with an increasing of the angle. If the filter is inserted inside the cavity and dye solution is excited, it is expected that the linewidth of the output spectrum becomes narrower than that of the filter itself during round-trip times, and the output peak power increases at the wavelength tuned with the filter. It is easily possible to get desired wavelengths by changing tilt angle of the filter mechanically. In order to get the laser power simultaneously at the multi wavelengths, two or more filters should be used as tuning elements. If we use a cavity containing two dye cells as shown in Fig.1(b), it is easy to get simultaneously two laser beams separated spatially at the two wavelengths. A schematic diagram of simultaneous two-wavelength dye laser which emits the laser beam into the same optical path is shown in Fig.1(c). The light is reflected by the 1st filter F1 over almost the whole wavelength region except to the transmitted wavelength,

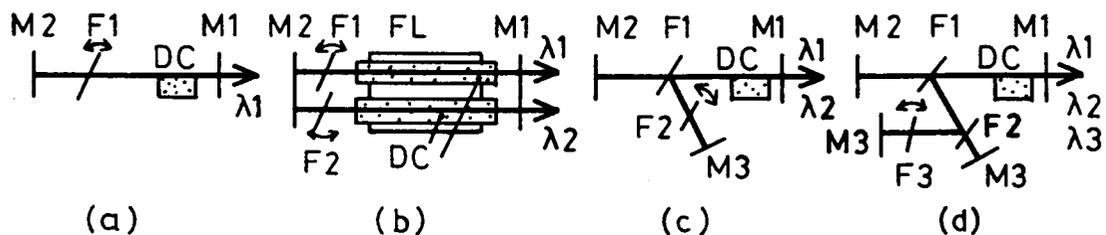


Figure 1. Schematic diagrams of the laser cavity with filters to get the simultaneous tunable multi-wavelength output. (a) Single wavelength¹⁾. (b) and (c) Two-wavelength²⁾³⁾. (d) Three-wavelength⁴⁾. (a), (c) and (d) are nitrogen laser pumped type. (b) is flashlamp pumped type. M;mirror, F;filter DC;dye cell, FL;flashlamp.

λ_1 , which is tuned by M1 and M2. The 2nd filter F2 is inserted into the 2nd cavity consisting of M1-F1-M3 which is tuned at the 2nd wavelength λ_2 . Each power of λ_1 and λ_2 is amplified in each cavity during roundtrip times. A simultaneous three-wavelength dye laser is constructed in the same manner as shown in Fig.1(d).

Many commercial filters with various characteristics were prepared and examined in experiments. Fig.2 shows typical examples of the simultaneous two- and three-wavelength spectra for a nitrogen laser pumped dye laser, where the linewidths of filters were 2nm at the incident angle 0° . Two wavelengths were tuned at the maximum (463.1nm) and minimum (465.8nm) absorption wavelength of NO_2 in the two-wavelength operation. Linewidths of the output were 0.4nm and the peak power was about 2.5 times of that obtained by the filter setting outside the cavity. The linewidth and the power were nearly constant and independent of the tilt angle of the filter. In the flashlamp pumped type, the linewidth and the power were halved and doubled, respectively, as compared with those obtained in a double prism tuning method. Also the linewidth obtained in the two-wavelength operation were one fourth of those obtained in the filter itself. In the nitrogen laser pumped type, fluctuations of the simultaneous three-wavelength operation were larger than those of the single- and simultaneous two-wavelength operation, in which the same pumping power was supplied.

In the filter tuning method, the high transmittance filter was better to get a good quality of the output spectrum, as the linewidth was narrowed during roundtrip times. When the

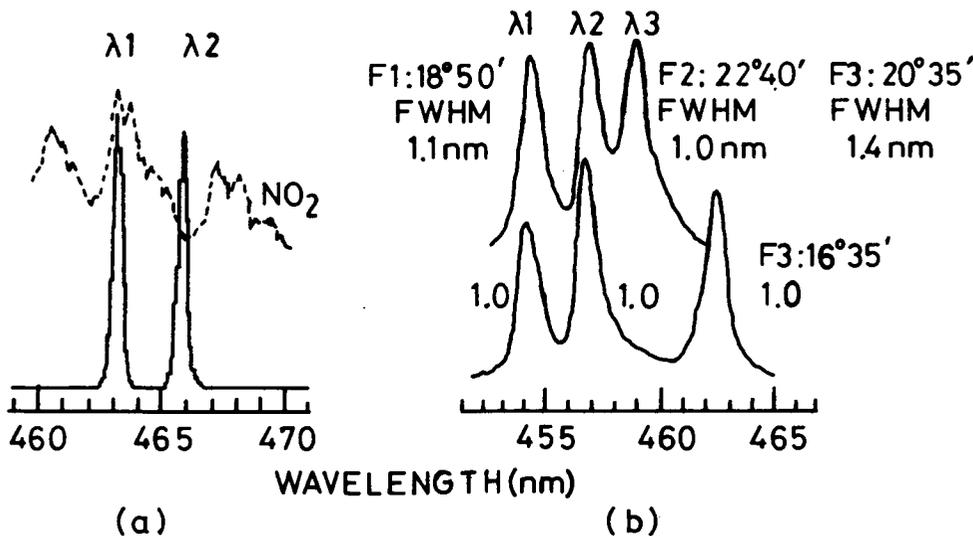


Figure 2. Output spectra of nitrogen laser pumped dye laser. (a) Two-wavelength³⁾; λ_1 and λ_2 are tuned NO_2 absorption spectrum (dashed line). (b) Three-wavelength⁴⁾; λ_3 shifts to shorter one with increasing the tilt angle of F3.

three wavelengths are tuned adequately, it is possible to measure simultaneously some molecules like NO_2 and SO_2 , and O_3 , NO_2 and aerosol density and so on.

Two types of DIAL systems, a long-path absorption type using a nitrogen pumped dye laser (5kW, 5ns, 10pps; Fig.1(c)), and range resolved type using a coaxial flashlamp pumped dye laser (5mJ, 300ns, 0.2pps; Fig.1(b)), were constructed and tested to confirm the feasibility in outdoor experiments. A two-wavelength beam was emitted to an atmosphere through a 10-power expander. In the receiving system, a telescope of the refracting type with a Fresnel lens of 50cm in diameter, two photomultipliers with two narrow band pass filters (0.35nm at FWHM), two wide band amplifiers (DC-50MHz) and a dual operation fast A/D converter (10ns/sample, 8bit) were used to detect simultaneously the signals at the two wavelengths and a micro-computer (16bit) was used as a processor.

A measurement of NO_2 concentration was made by the system in the stack which was set on a building located at the distance of 513m from the system. There was a national road in a heavy traffic along the building. In experiments, a concrete wall of this building at the back of the stack was selected as a topographic target. Fig.3 shows an example of results obtained in the long-path absorption DIAL system. The minimum detectable concentration of this system was about 20ppb at a total distance of 1.0km on a condition of shot noise. The peak concentration of NO_2 was 237ppb, which would correspond to the value of 24ppm.m if the plume passed the laser beam over 5m in length. Error bars of the experimental data were bigger than those when the plume was exhausted. This is caused from the NO_2 concentration being heavily changed and that the transmit-

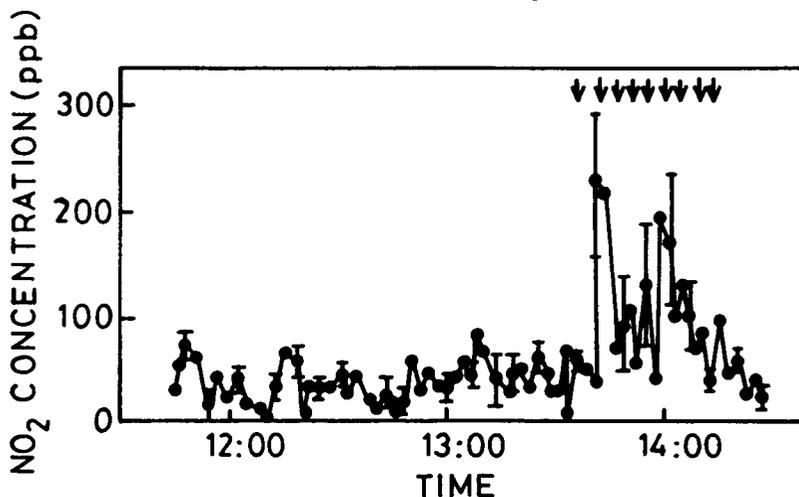


Figure 3. Time variations of NO_2 concentration in a stack plume at 513m from the DIAL system using a long-path absorption type by averaging 1000 signals. Arrows show the times when the plume could be observed by the naked eye⁵⁾.

tance of the plume was changed continuously because of the heavy changing of the density of the soot and smoke during the averaging time (90sec., 1000signals). Actually there was the case that the returned signal from the target could not have been obtained because of the large amount of absorption and scattering by the plume. This result implies that the numbers for averaging should be determined after the consideration about both the time variation of the concentration and the repetition rate of the laser pulse in order to get exactly the short time variation within a allowable error. This is an important thing in the measurement at the place where the concentration changes heavily and continuously like a stack plume or an intersecting point of a heavy traffic road. It may be assumed that many small variations out of the plume are caused from the traffic. In the range-resolved DIAL system, the NO₂ concentration was measured with 75m range resolution by averaging 50 signals (5 minutes) up to 300m, but the minimum concentration was comparatively large because the energy of the laser was not so large.

From these experimental results, the following things are concluded. A dielectric multilayer interference filter is a good tuning element if it is inserted into the laser cavity. A simultaneous tunable multi-wavelength dye laser can be made easily in combination with some filters. The dye laser with this filter tuning method is a useful apparatus in outdoor experiments when it is applied to the system like a DIAL system because of the simplicity of the cavity construction and the easiness of the tuning. It may be possible to measure some pollutions simultaneously using this simultaneous multi-wavelength dye laser and to apply it to many physical and chemical regions.

References

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