Hybrid Titanium-Sapphire: Dye laser

Carlos Gerardo Treviño-Palacios, Oscar Javier Zapata-Nava and M. David Iturbe-Castillo
Instituto Nacional de Astrofísica, Óptica y Electrónica
Apdo. Postal 51 y 216 Puebla, Pue. 72000, México
E-mail: carlost@inaoep.mx

Abstract. On this work we present a Titanium:Sapphire laser with an intracavity dye amplifier. The system was pumped with 5 W of 532 nm laser radiation from an intracavity doubled Nd:YVO4 laser. The dye used was styryl 14 dye dissolved in a 15%:85% combination of ethylene glycol and propylene carbonate solvents inside a flow cell. The laser was tuned using a three-stage birefringent filter. We observe the behavior of the system in which the intracavity amplifier, depending on the pump power, behaved as an amplifier, hybrid laser or saturable absorber.

1. Introduction
For spectroscopic studies a tunable sources at the wavelengths of interest is required. We are particularly interested in the study of medical applications in the near infrared region and at long wavelengths, particularly Terahertz. In the development of sources of two wavelengths for the generation of terahertz sources requires that the system is inhomogeneous broadening (such as semiconductor laser, optical fiber or dye) and it is desirable to have a long wavelength so that the separation between the wavelengths is clear and has a separation in the order of terahertz.

For a source emitting in the terahertz region, specifically at 300 microns (1 THz) we are looking for a system emitting simultaneously at two wavelengths, separated a few nanometers for Terahertz radiation by nonlinear difference frequency. Previously we presented a birefringent filter with a characteristic curve in two wavelength [1] and a dye system emitting at two wavelength[2].

In this paper we present a hybrid laser system with two gain media, one homogeneous and other inhomogeneous both operating simultaneously. Tunable systems that used dyes with broad gain curve are inhomogeneous with many energy levels with Stark splittings. Given the populations on these systems configurations which have a high threshold for laser emission are used and is necessary to use pulsed sources. On the other hand systems with broad gain curves of solid state, as the titanium-sapphire (Ti:Sapphire) or chromium, strontium-aluminum-fluoride (Cr:LiSAF) behave regularly as homogeneous systems. We combined both in what is known as a hybrid lasers [3-5] using two laser gain media coupled in a single cavity. Here we present a titanium-sapphire laser (Ti:Sapphire) with an intracavity dye amplifier as a hybrid system.
2. Cavity design

The system configuration is shown in figure 1, in which the first stage has a titanium-sapphire crystal as gain medium and the second has styryl 14 dye (5,6-dichloro-2-[8-(p-dimethylaminophenyl)-2,4-neopentylene-1,3,5,7-octatetraenyl]-3-ethylbenothiazolium perchlorate; or Benzothatiazolium, 5,6-dichloro-2-[[3-[4-[4-(dimethylamino)phenyl]-1,3-butadienyl]-5,5-dimethyl-2-cyclohexen-1-ylidene]methyl]-3-ethyl perchlorate; LDS 950 in the Exciton catalogue) dissolved in an 85% ethylene glycol (EG) and 15% propylene carbonate (PC) solution [6, 7]. The dye circulated uniformly on a 40 mm long quartz cell over a 4 mm aisle between a Teflon separator and the transparent front window used as pumping window (Radiant Dyes Laser Acc. GmbH, RDFC40). The pump beam was expanded to illuminate the length of the cell and focused using a cylindrical lens on a 15 mm width beam spot. Both stages are coupled with a 95% transmission flat mirror. The system is pumped using a 5W Coherent Verdi laser (SHG:Nd:YVO4). We can control the pump power for each gain medium with the combination of a plate $\lambda/2$ and a polarizing beam splitter (PBS).

If we only consider the Ti:Sapphire stage (from M1 to M5), the system has a 3.4 W threshold. In the dye stage of the system, the styryl 14 dye strongly absorbs in the blue-green region of the spectrum and emits in the infrared. The fluorescence spectrum of this dye is shown in the figure 1 inset. The dye concentration was increased to obtain the maximum gain at a fixed pumping power. The final molar concentration was $3.6 \times 10^{-5}$M. The dye flow cell is of quartz and has a constant flow of dye with a propagation length of 40 mm with a width of 2 mm between a teflon surface and a quartz window.

The entire cavity is therefore formed from the mirror 100% (M1) to the 90% output coupler (M6). The Ti:Sapphire cavity length (M1-M5) is 133 cm, the entire hybrid system cavity (M1-M6) is 212 cm. Depending on the pump power the entire laser has 3 distinctive behaviors, described in the next section.
3. Results

As mentioned, depending on the pumping power, the system has different behavior. Taking as a reference the laser characteristic for the Ti:Sapphire stage (mirrors M1 to M5), shown in figure 2, we can describe the observations. We split the total useful pump power (4.6 W) among both gain mediums in order to have the maximum power available shared between both gain medium in the system. Using a chopper in the pump beam for the dye gain stage, in such a way that the gain in the dye stage is modulated we recorded the different responses at 910 nm in a large area silicon detector and an oscilloscope.

![Figure 2. Laser characteristic curve for the Ti:Sapphire stage (M1-M5 in figure 1) with a laser threshold of 3.4 W. The arrows denote the pump power for the different hybrid laser responses.](image)

If the pump is far below threshold ($I_{\text{pump, Ti:Saf}} = 2.6$ W, $I_{\text{pump, dye}} = 2.0$ W) we observe the amplified fluorescence from the titanium sapphire through the dye gain medium (figure 3a). When the chopper blocks the dye pump beam we have the upper trace background signal corresponding to the parasite light added to the gain medium fluorescence. When the chopper is open this signal increases (lower segmented signal in figure 3a).

Somewhere below the threshold power ($I_{\text{pump, Ti:Saf}} = 3.1-3.2$ W, $I_{\text{pump, dye}} = 1.4-1.5$ W) the system presents a hybrid laser system, this is, the cavity from M1 to M6 must be aligned as an stable cavity and we require both gain medium to be present and having pump on both mediums (figure 3b). When the chopper blocks the dye pump beam we have the upper trace background signal corresponding to the parasite light added to the gain medium fluorescence, somehow larger than the one in figure 3a. When the chopper is open the system stars lasing and we have a much larger signal into the detector. This was an unexpected result because there must be pump light in both systems, and if any of the mirrors is misaligned the laser action ceased. This is we have a hybrid laser system.

When the pump is above threshold for the Ti:Sapphire stage ($I_{\text{pump, Ti:Saf}} > 3.4$) the coupled system behaves as a regular oscillator-amplifier system (figure 3c). Chopping the pump into the dye gain medium stage increases the signal coming from the Ti:Sapphire laser.
Figure 3. Oscilloscope traces for the dual laser system working as (a) amplifier fluorescence, (b) hybrid laser system, and (c) Oscillator-amplifier system

4. Conclusions
We have shown a laser operating simultaneously with two gain media, or a hybrid laser. This response was observed under certain pumping conditions between a fluorescent source and a amplified laser system, depending on the laser threshold of the Ti:Sapphire stage.

Acknowledgments
This work was financed by mexican grant CONACyT-SALUD-2005-01-14012.

References
[1] Corinna Wetzel and Carlos G. Treviño Palacios 2007 Memoria Arbitradas de la XX Reunión Anual de Óptica, ed Fermín Salomón Granados Agustín, Perla Carolina García Flores and Ana Ma. Zárate Rivera (Academia Mexicana de Óptica, Mexico) ON-01
[2] Oscar Javier Zapata Nava, David Iturbe Castillo and Carlos Gerardo Treviño Palacios 2008 Láser de colorante infrarrojo emitiendo en dos longitudes de onda Memorias en Extenso Arbitradas de la XXI Reunión Anual de Óptica ed Fermin Salomón Granados Agustín, Perla Carolina Garcia Flores and Ana Ma Zarate Rivera (Academia Mexicana de Óptica, Mexico)
[3] Y F Chen, Y P Lan and S C Wand, 200 Opt. Lett. 25, 1016–1018
[4] P. K. Mukhopadhyay, J. George, S. K. Sharma, P. K. Gupta, and T. P. S. Nathan, 2002 Pramana – J. Phys 58, 59-66
[5] S. Han and L. Yan, 2008 PIERS Proceedings, Hangzhou, China (2008) 1320-1305
[6] K. Kato 1984 Opt. Lett. 9 544-545
[7] S. O. Kanstad and G. Wang 1978 Appl. Opt. 17 87-90.