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TITANIUM: SAPPHIRE LASER PUMPED BY COPPER VAPOR LASER

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Abstract

In this paper we describe the applications of a Ti:Sapphire laser pumped by a copper vapor laser (CVL). We calculated and constructed an astigmatically compensated cavity for CVL pumped solid state lasers. The characteristics of our laser are interesting in the application of spectroscopy. With intracavity experiments high sensitivity was obtained over a large spectral range. We demonstrate, using I₂ as a test molecule, that the extreme sensitivity of intracavity stimulated emission pumping (SEP) is due to non-linear effects which result in mode-locking.

The advent of the high repetition rate (5-20 kHz) and high efficiency (~1%) CVL has produced an ideal spectroscopic tool. The CVL (Oxford Lasers Cu 60) operates at the wavelengths 511 nm and 578 nm which are both suitable for pumping Ti:Sapphire. We have calculated and constructed a longitudinally pumped Ti:Sapphire laser with an astigmatically compensated Z-shaped cavity (fig.1).

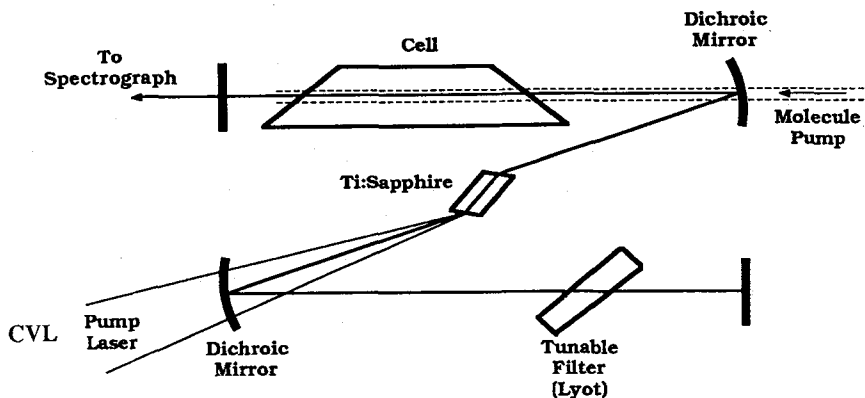


Figure 1.

The pump threshold for the Ti:Sapphire is 0.6 Watt and its efficiency is about 25%. Typically an output power of 1 W (≈ 1 kW peak power) is obtained with a pump power of 4 W and with a 3 plates intracavity Lyot filter (bandwidth ≈ 1 Å) the reflectivity of the output mirror being 97%. The gain of the Ti:Sapphire crystal has a range of 680 nm to 1100 nm, with a maximum at 800 nm [1]. Our set of mirrors permitted us to operate in the region from 700 nm to 840 nm. Figure 2 shows the temporal evolution of the radiation. At first there is the pulse of the CVL and after a delay of about 200 ns the pulse of the Ti:Sapphire laser is produced. The Ti:Sapphire pulse is very dissymmetric with a long tail. Its full width at half maximum (FWHM) is about 300 ns and the whole period of time above threshold is about 3 μ s. Depending on the pump power we observed some nonlinear oscillations.

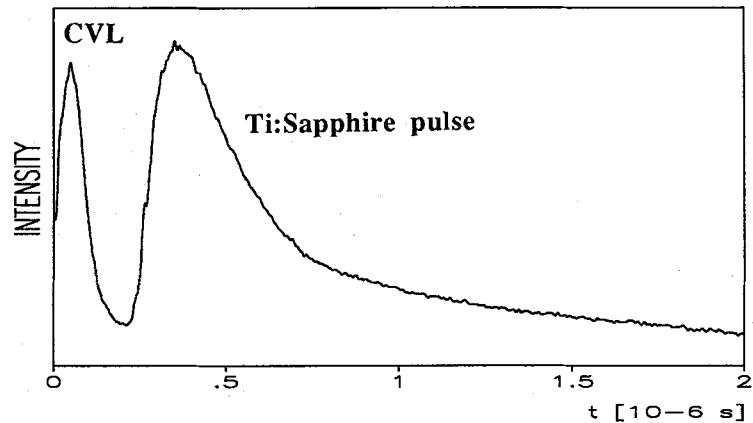


Figure 2.

From intracavity experiments a higher sensitivity is expected. Taking the time above threshold as the generation time t_g of a spectrum for incoherent operation (without mode-locking) we determine the equivalent length l_{eq} of a gas cell [2] (and Ref. therein)

$$L_{eq} = \frac{L_{cell}}{L_{cavity}} c t_g$$

where L_{cell} = optical length of the intracavity cell
 L_{cavity} = optical length of the cavity
 c = speed of light

With the values of our experimental setup $L_{cell} = 12$ cm, $L_{cavity} = 66$ cm we obtain $t_{eq} \approx 160$ m. This means that we have a 10^3 times higher sensitivity from intracavity experiments than from extracavity experiments.

We will show experimentally that a mode-locked situation increases greatly the sensitivity of intracavity stimulated emission pumping (SEP) spectroscopy.

We performed intracavity absorption experiments with O_2 , C_2H_2 and CS_2 . As an example we show a spectrum of C_2H_2 at a wavelength of 787 nm in figure 3.

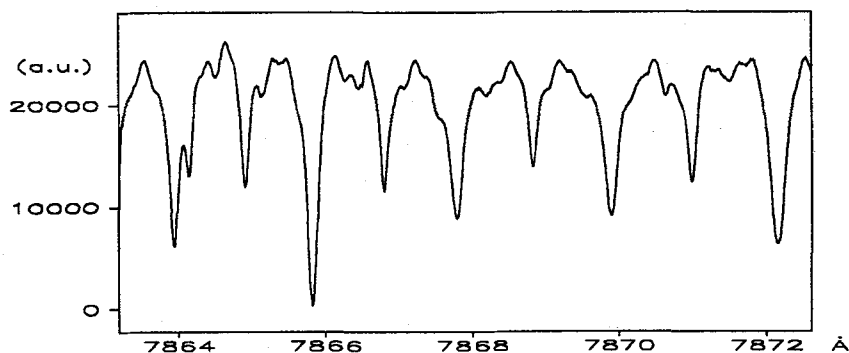


Figure 3.

The high peak power permits us furthermore to use the Ti:Sapphire laser for nonlinear effects like frequency doubling and multiphoton spectroscopy. To examine this capability we performed an intracavity SEP with the test molecule iodine. SEP is a double resonance technique which excites the molecule by the pump radiation and stimulates an emission by the dump radiation (fig.4). For pumping I_2 we injected the CVL radiation at 578 nm into the cell and for dumping the molecule we used the tunable Ti:Sapphire laser. As a tuning element a Lyot filter was placed inside the cavity. The experimental setup is shown in figure 1

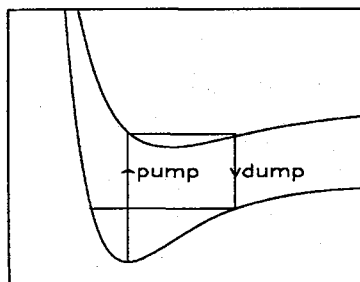
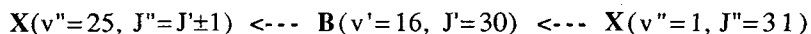


Figure 4.

We detected with a very high sensitivity iodine emission lines, where the base of the Ti:Sapphire spectrum disappeared completely. The Ti:Sapphire laser operated only in these emission lines of I_2 . Figure 5 shows the P-R-doublet corresponding to the transitions [4]



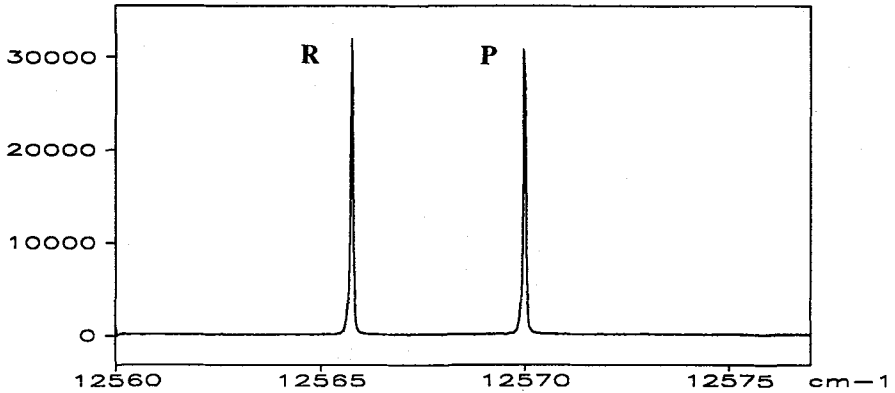


Figure 5.

The threshold for the disappearance of the base was ≈ 1 mW and the threshold for detection of stimulated emission was estimated, due to the lack of a finer pump reduction, to be some tens of μW . It is quite remarkable that while operating at the I_2 emission lines the Ti:Sapphire laser was mode-locked. We observed an oscillating structure of the pulse with a period of 4.4 ns which is the time for a roundtrip of a photon inside the cavity with an optical length of 66 cm. The train of impulses was approximately sinusoidal in form which means that very few laser modes were correlated. Looking at the distance between two laser modes of about 230 MHz and taking into account that the Doppler-width of I_2 is about 1 GHz we determined that 2-4 laser modes were excited. Thus I_2 served as a saturable gain [5]. We believe the extreme sensitivity due to the fact that the correlation length of modes in the Ti:Sapphire laser is of the same order as the Doppler-width of I_2 .

The appearance of the mode-lock made it possible to detect the SEP spectrum from the laser signal which was modulated at the repetition frequency of the mode locked pulses. This could indeed lead to a new kind of spectroscopy.

Having demonstrated mode-locking by means of a saturable gain we continued to look for other ways of provoking mode-locking in our Ti:Sapphire laser. We discovered that the Ti:Sapphire laser at low pump power is always mode-locked while containing a selective element inside the cavity like a Lyot filter. However, a stable train of short pulses with the baseline at zero is only obtained if the spectral band of the Ti:Sapphire laser is within the correlation length of modes. With an etalon and a Lyot filter with three plates we received a 7 GHz large band. The mode-lock that we got

was very stable. The duration of a single impulse was about 300 ps which reflects the Fourier transform of the spectral band. Figure 6 shows one impulse recorded with a 50 GHz sampling oscilloscope.

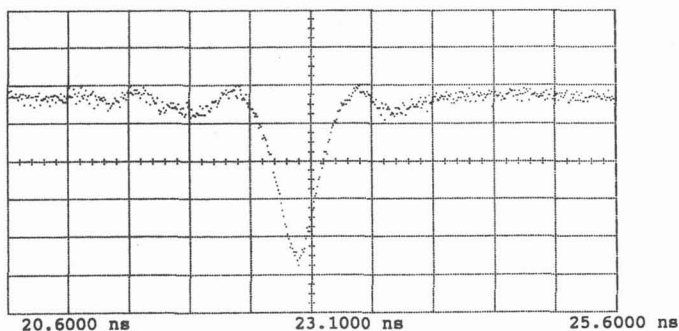


Figure 6.

Conclusion

We describe the capability of the Ti:sapphire laser pumped by a CVL for spectroscopic applications. Some of the spectroscopic qualities depend on the remarkable dynamics of the laser, especially the mode-lock. Self mode-lock was obtained with a selective element inside the cavity. 300 ps long Fourier transform limited impulses could be observed.

Acknowledgements

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