Properties of Titanium - Sapphire Lasers

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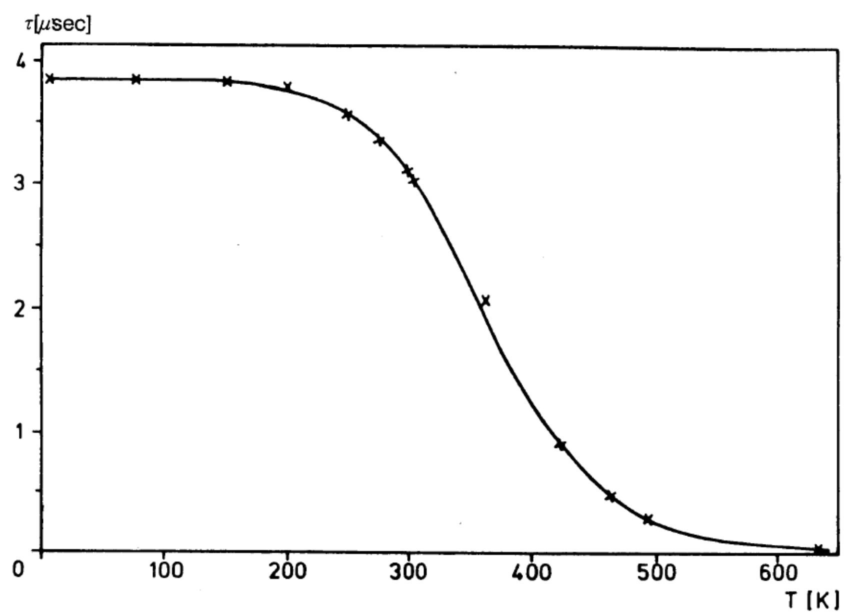
An overview of many various properties of Ti:Sapphire lasers and applications of such lasers will be seen.

The first instance of a Ti:sapphire was reported during the Twelfth International Quantum Electronic Conference in Munich in June 1982. Since that time, a vast array of laser systems have been created using the Ti:sapphire medium.

The properties of Ti:sapphire lasers can be quite disperse due to the wide variety of possible pumping mechanisms. These mechanisms are most always in the form of another type of laser; however, the original laser design involved using a flash lamp. Common currently used pumps include dye lasers, argon ion lasers, and ND:YAG lasers. The properties of these pump lasers have a large affect on the properties of the Ti:sapphire laser.

The gain medium, Ti:sapphire, is closely related to the original Ruby laser. Sapphire, or more generally corundum, is the compound aluminum oxide, Al_2O_3. The only difference between ruby and sapphire is that a chromium impurity gives ruby a deep red color, all other corundum is called sapphire. A sapphire with a titanium impurity is light red in color.

The Ti:sapphire laser is a four level system. The laser transition occurs between the ^2E and $^2T_2$ levels. The decay time for the upper laser level can range from 4μs to just above zero. This corresponds to a decay rate ranging from 250 to 333 kHz. Below is a plot of upper level decay time as a function of temperature.



In an early experiment to investigate gain of Ti:sapphire, the following was discovered. Using a krypton-ion probe beam at 676.5nm and an argon-ion laser at 514.4nm, a gain of $1*10^{-2}$ per watt of pump power was found. This resulted in a gain cross section of $6.8*10^{-20}$ cm^2.

Depending on the specifics of the laser system, Doppler or collisional broadening can be observed; however, homogeneous broadening is the most often observed case.

The Ti:sapphire medium is desirable due to its tuning and absorption range. The absorption range is 400-600nm. This property is what allows a variety of pumps to be used. Ti:sapphire has a tuning range of 660-1050nm, which ranges from red to infrared.

In a report early in Ti:sapphire laser research, quantum efficiency was studied. A quantum efficiency of 80% was found at room temperature under continuous wave operation. This quantum efficiency is the ratio of pump photons to the laser transition photons.

Single and multimode operations are both possible. At low pump energies, the TEM_{00} mode occurs. While at increasing energies, higher multimodes occur.

Pulsed and continuous wave operation is possible. Pulsed operation is what makes the high power outputs possible. More specifically, the most powerful Ti:sapphire lasers use what is called chirped pulse amplification. This is the process of stretching the pulse out by passing through a diffraction grating. This is done so amplification can occur without damaging the crystal. After amplification, the beam is the compressed back down to a short pulse and focused before exiting the system.

An average output power of 3W is possible at 10 kHz operation. In late 2007, a possible power output record was made using a Ti:sapphire laser. At the University of Michigan, a 30fs pulse beam was created with 300TW of power giving an intensity of $1*10^{21}$ W/cm^2. This beam was had a spot size of 1.3 μm.

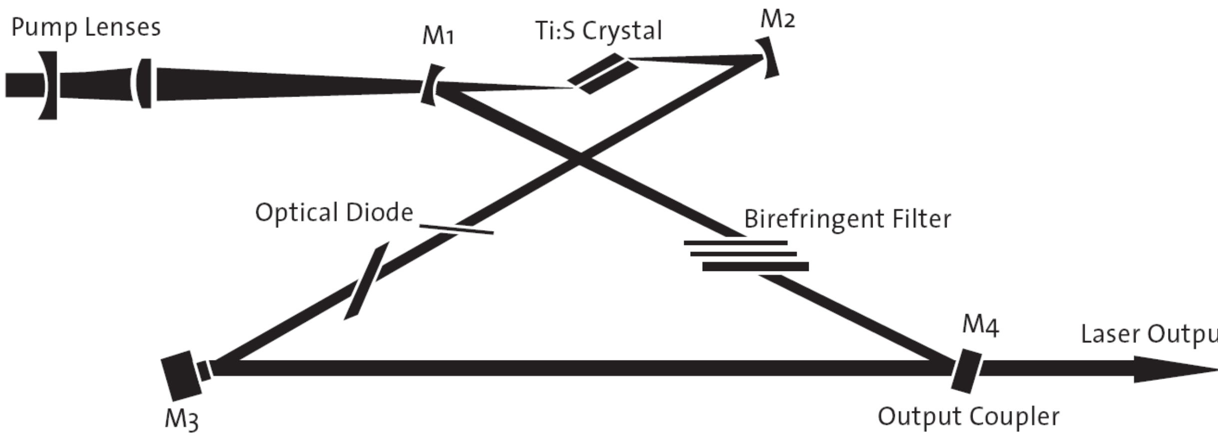
Many different cavity arrangements can be used, depending on the intended application. Typical cavities used in the early stages of research into Ti:sapphire operation were on the order of tens of centimeters.

Spectral purity is a measure of how close the output is to remaining at a constant wavelength. Spectral purity of up to 99% has been achieved.

A half angle divergence of 1.7 mrad is typical.

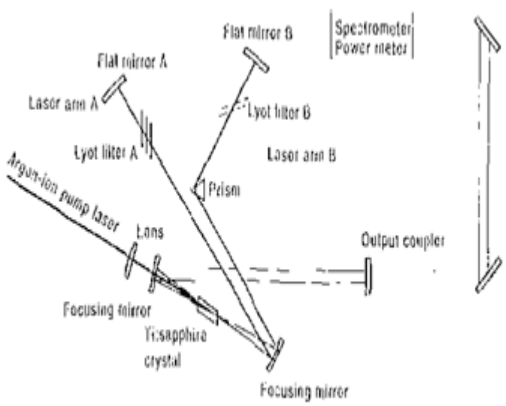
Typical maximum coherence length is on the order of a few millimeters. A typical length is on the order of micrometers.

The size of the laser system is dependent of what the desired output/outcome of an experiment is. For the record setting University of Michigan laser mentioned above, the entire setup occupies several rooms.

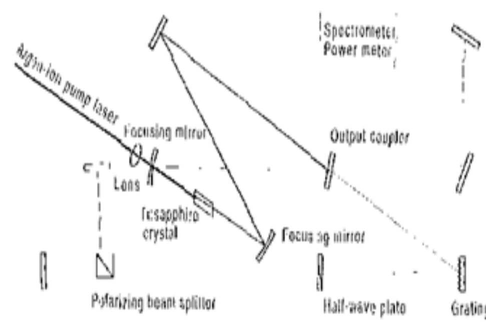


This setup is simply a stock “laser in a box” that one can purchase from a laser manufacturer. The box size is on the order of a large reference book.

The two configurations below are both used to create a two-color output using a single Ti:sapphire crystal and cavity setup. These setups are used to produce continuous wave output on the order of terahertz.



CThM67 Fig. 1. Schematics of the resonator design of the linear α-cavity.



CThM67 Fig. 2. Schematics of the resonator design of the ring cavity.

With the recent high power laser systems, Ti:sapphire lasers are looking to be the front runners in using lasers for vacuum breakdown and inertial confinement fusion. Although not yet proven practical, the use of Ti:sapphire lasers in medical applications are being studied. Due to the lasers short penetration depth, possible uses in the field of dermatology are possible.

The Ti:sapphire laser has proven, in a short amount of time, to be a widely versatile system. With a wide array of operating parameters, this laser medium is showing possibilities in many fields. Although most of the current uses of this laser are only academic, many scientists see practical applications on the horizon.

References:

P. Albers, E. Stark, and G. Huber, "Continuous-wave laser operation and quantum efficiency of titanium-doped sapphire," J. Opt. Soc. Am. B 3, 134-139 (1986)

P. F. Moulton, "Spectroscopic and laser characteristics of Ti:Al_2O_3," J. Opt. Soc. Am. B 3, 125-133 (1986) http://www.opticsinfobase.org/abstract.cfm?URI=josab-3-1-125

Laser Fundamentals. William Thomas Silfvast, Edition: 2, illustrated, revised. Published by Cambridge University Press, 2004

Observation of delayed bifurcations at the threshold of a Ti:sapphire laser J I Alexander *et al* 1995 *Quantum Semiclass. Opt.* 7 467-478

Siebert, K.; Siebe, F.; Roskos, H.G.; Leonhardt, R., "A two-color Ti:sapphire laser for CW-THz generation," *Lasers and Electro-Optics, 2000. (CLEO 2000). Conference on* , vol., no., pp.497-, 2000
http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=907303&isnumber=19501

V. Yanovsky, V. Chvykov, G. Kalinchenko, P. Rousseau, T. Planchon, T. Matsuoka, A. Maksimchuk, J. Nees, G. Cheriaux, G. Mourou, and K. Krushelnick, "Ultra-high intensity- 300-TW laser at 0.1 Hz repetition rate," Opt. Express 16, 2109-2114 (2008) http://www.opticsinfobase.org/abstract.cfm?URI=oe-16-3-2109

Sungmo Nam; Jaemin Han; Yongjoo Rhee; Yongwoo Lee; Yong-Ho Cha; Hyung Ki Cha, "Neutron generation induced by laser fusion by using a 10TW femtosecond Ti:Sapphire laser," *Lasers and Electro-Optics - Pacific Rim, 2007. CLEO/Pacific Rim 2007. Conference on* , vol., no., pp.1-2, 26-31 Aug. 2007
http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=4391755&isnumber=4391084

MBR-01 Ti:sapphire laser. Coherent Inc., http://coherentinc.com/downloads/MBR01_DS_3.pdj

Titanium Doped Sapphire. Eksma Optics., http://www.eksmaoptics.com/en/p/titanium-doped-sapphire-ti-sapphire-305