Saturable Absorber Mirrors For Passive Mode-locking

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Introduction

Saturable absorber mirrors (SAMs) are inexpensive and compact devices for passive mode-locking of diode pumped solid state lasers. Such laser systems can provide ultrashort pulse trains with high repetition rates. Typical values for pulse duration ranging from 100 fs up to 10 ps. For instance a Nd:YAG laser can be mode-locked with pulse duration of 8 ps and mean output power of 6 W.

On this poster we present results for a Yb: KYW laser passive mode-locked by SAMs with three different modulation depths between 0.6% and 2.0%. SAMs were prepared by solid-source molecular beam epitaxy with a low-temperature (LT) grown InGaAs absorbing quantum well.

Requirements for passive mode-locking

The mode-locking regime is stable agaist the onset of multiple pulsing as long as the pulse duration is smaller than t_{min}. (*)

$$t_{min} \approx \frac{\sqrt{D_{g,f}}}{2}\,\frac{1}{\sqrt{DR}}\,f\left(\frac{E_P}{E_A}\right)$$

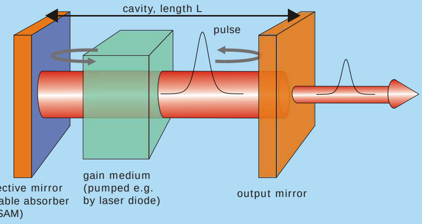
$D_{g,f}$ gain and filter losses
DR modulation depth
E_P pulse energy
E_A saturation energy
$f(E_P/E_A)$ a function which has a minimum at E_P/E_A between 2 and 3

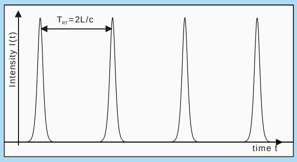
Saturable Absorber Mirror (SAM)

schematic laser set-up

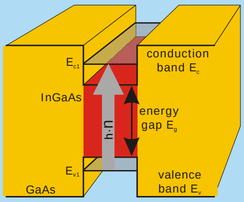
- cavity with gain medium
- high reflective mirror and output mirror with partially transmission
- saturable absorber as modulator

=> pulse trains spaced by round-trip time $T_{RT}=2L/c$

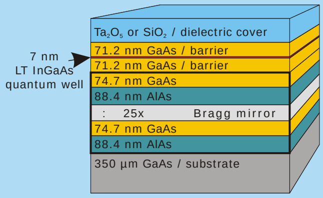




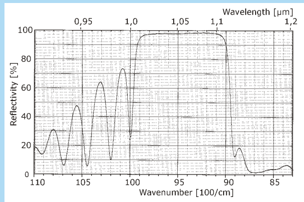
LT InGaAs quantum well



SAM design



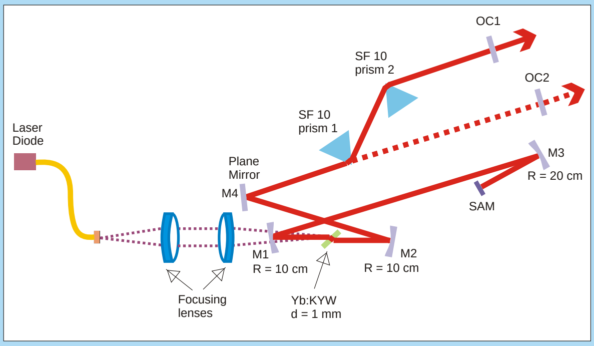
SAM reflection spectrum



- tunable absorption wavelength via thickness and In content
- fast recovery time of the absorbing low-temperature (LT) grown InGaAs film

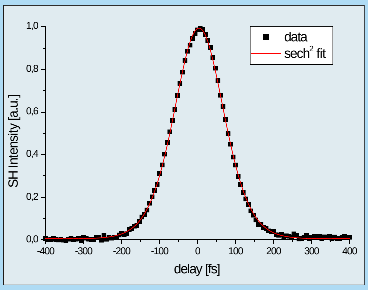
- layers are grown by solid-source molecular beam epitaxy
- Bragg-mirror with wide high reflection band (R>99.7%)
- embedded absorbing InGaAs quantum well
- dielectric protection layer

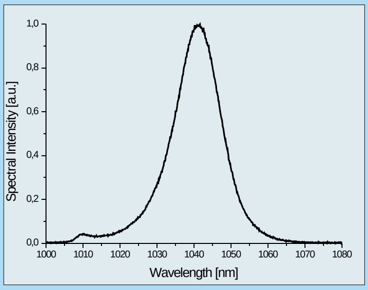
Experimental set-up for the mode-locked Yb:KYW laser



M1 -M3, curved mirrors; R, radius of curvature; M4, high-reflective plane mirror;
OC1-OC2, output coupler with different transmissions; SAM, saturable absorber mirror
Active media: 1-mm thick Yb:KYW crystal, 5 at% of Yb^{3+} ions, pumping along b axis
Pumping system: fiber coupled high-brightness laser diode, output power up to 5 W
Measured pump spot diameter in the crystal: 100 µm
Laser beam radius onto the SAM: ~ 83 µm
Dispersion compensation: SF10 prisms separated by 34 cm

Autocorrelation trace and optical spectrum of 100-fs pulses





The autocorrelation trace (left) and the corresponding optical spectrum (right) of the shortest pulses delievered from the Yb:KYW laser. They were obtained using a 2% modulation depth saturable absorber and an 1% transmission output coupler. The red line shows the theoretical curve assuming a pulsewidth of 100-fs and a $sech^2$ - pulse shape. The spectrum is centered at 1041 nm and has a bandwidth of 14.2 nm FWHM. The output power was 52 mW at a pump power of 4.4 W.

Laser parameters achieved for different modulation depths DR

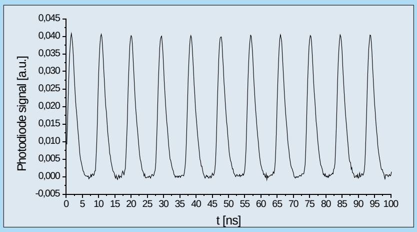
DR (%)	t_{FWHM} (fs)	P_{out} (mW)	T_{OC} (%)	P_{pump} (W)
0.6	**160**	53	1	3.0
	198	**292**	4	4.5
1.2	**140**	63	1	3.2
	156	**228**	4	4.5
2.0	**100**	52	1	4.4
	134	**136**	4	4.5

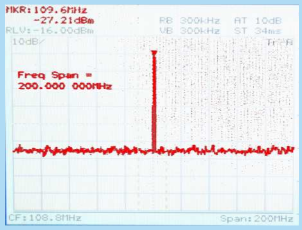
t_{FWHM} pulsewidth, P_{out} laser output power, T_{OC} output coupler transmission, P_{pump} pump power.
The minimum pulsewidth and the maximum output power are indicated with bold letters.

For a given value of the modulation depth, t_{min} is dependent on the total cavity loss (including the output coupler transmission T_{OC}) and on the intracavity pulse energy. In order to get the minimum pulsewidth, we tested output couplers with different transmissions. The pulse energy was modified by varying the pump power.

Similar results were obtained with a Yb:KGW laser. (**)

Pulse train and frequency spectrum





The pulse train was recorded with a silicon photodiode with a rise time of 2 ns and a 500 MHz - oscilloscope. The frequency spectrum does not show bandsides.

(*) F. X. Kärtner, I. Aus der Au and U. Keller, "Mode-Locking with Slow and Fast Saturable Absorbers What's the Difference?", *Special Issue on Ultrafast Electronics, Photonics and Optoelectronics*, IEEE J. Select. Topics Quantum Electron. 4, 159-168 (1998).
(**) G. Paunescu, J. Hein, R. Sauerbrey, "100-fs diode-pumped Yb:KGW mode-locked laser", Appl. Phys. B (2004).

Summary

Saturable absorber mirrors (SAMs) were grown by low-temperature solid-source molecular beam epitaxy.

SAMs with modulation depths of 0.6%, 1.1% and 2.0% were used to mode lock a diode-pumped Yb:KYW laser at around 1040 nm.

The mode-locking regime was selfstarting and stable.

For some hours of continuously operation, we did not notice any damage.

The minimum achievable pulse duration and the output power decrease by increasing the modulation depth.

Pulses as short as 100 fs were obtained with a 2% modulation depth saturable absorber.