Conference Photonics 2016

Spectral polarization-encoding for broadband laser pulses basing on rotatory dispersion and its possible applications

Shixiang Xu, Shuiqing Zheng, Xinjian Pan, Xuanke Zeng, and Qinggang Lin

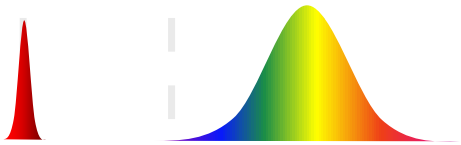
Shenzhen Key Lab of Micro-Nano Photonic Information Technology, College of Electronic Science and Technology, Shenzhen University, Shenzhen, Guangdong 518060, People's Republic of China

Email: shxxu@szu.edu.cn

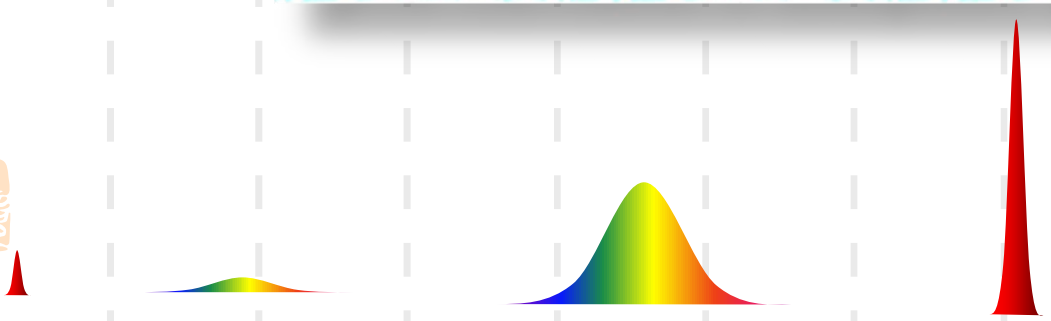
Outlines

1. Concept and realization of spectral polarization-encoding for broadband laser pulses;
2. Application-1: broadband amplification in Ti: sapphire laser systems;
3. Application-2: pulse spectral shaping;
4. Application-3: tunable laser;
5. Application-4: Terahertz polarization spectroscopy

1. Concept and realization of spectral polarization-encoding for broadband laser pulses



The shorter pulse duration, the broader spectral bandwidth, or more affluent spectral components: great convenient to manipulate spectrum.



Chirped pulse amplification (CPA): A revolution, has pushed ultrashort pulse up to peta-watt level .

*** Spectral time-encoding: for a chirped light pulse, different spectral component corresponds to different time (group velocity dispersion).**

Similar to CPA, we propose a spectral polarization-encoding: different spectral component vs. different polarization direction.

*** Realization by inducing optical rotatory dispersion (ORD).**

To produce ORD by using an optical active crystal: $\alpha(\lambda)=\eta(\lambda)L$.

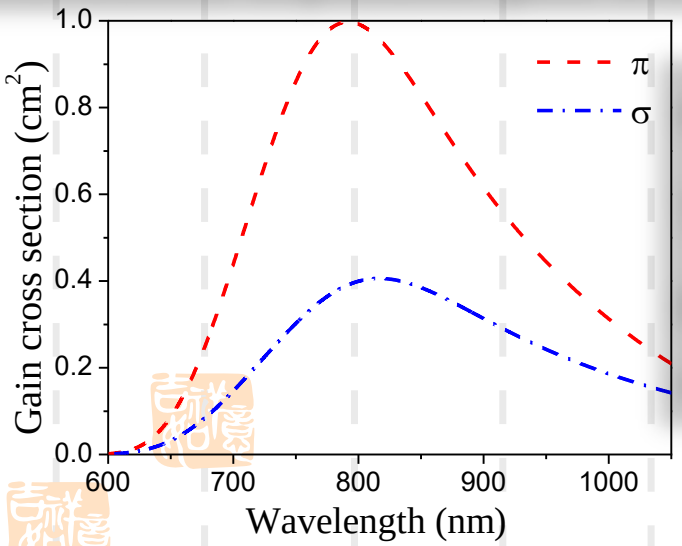
Input linearly polarized pulses → output linearly polarized pulses but different spectral components have different polarization directions.

*** Simple to implement, without need of applied magnetic fields, unlike, e.g., Faraday rotator;**

*** The ORD is perfectly compensable by doubly-passing the crystal or by passing another crystal with opposite chirality.**

2. Application-1: broadband amplification in Ti: sapphire laser systems

Polarization-dependent gain cross section of Ti: S



Gain cross section: $\sigma_\pi \approx 2.4\sigma_\sigma$

Traditionally, pulses are amplified with π-polarized (//*c* axis). Serious spectral narrowing occurs in a chirped-pulsed Ti: S amplifier.

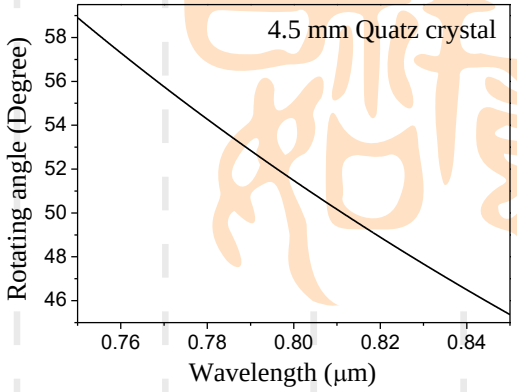
Spectral polarization-encoding: rotatory dispersion

$$\alpha(\lambda) = \eta(\lambda) L$$

***Basic idea*: the spectral components around the gain peak are amplified with close to σ-polarization, while the others are done close to π-polarization.**

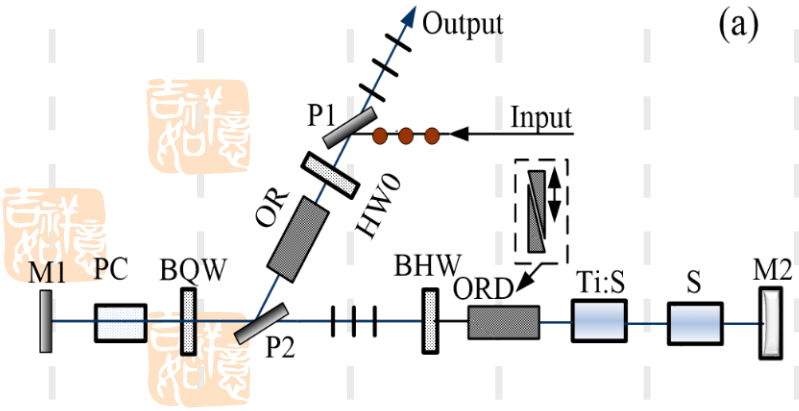
Laser Phys. Lett. 12, 085301(2015)

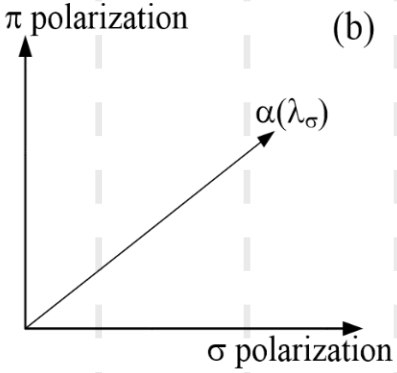
Quartz: $\eta(\lambda) = \frac{9.5639}{\lambda^2 - 0.0127493} - \frac{2.3113}{\lambda^2 - 0.000974} - 0.1905$

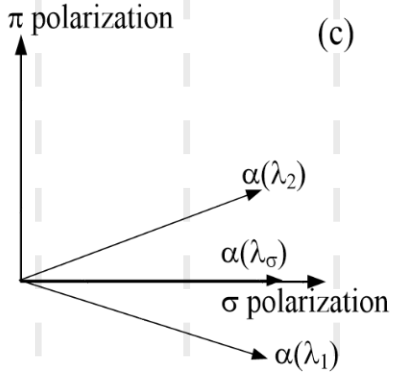


Realization: an optical rotatory dispersion (ORD) crystal and a broadband half-wave plate

Application in Ti: S regenerative amplification







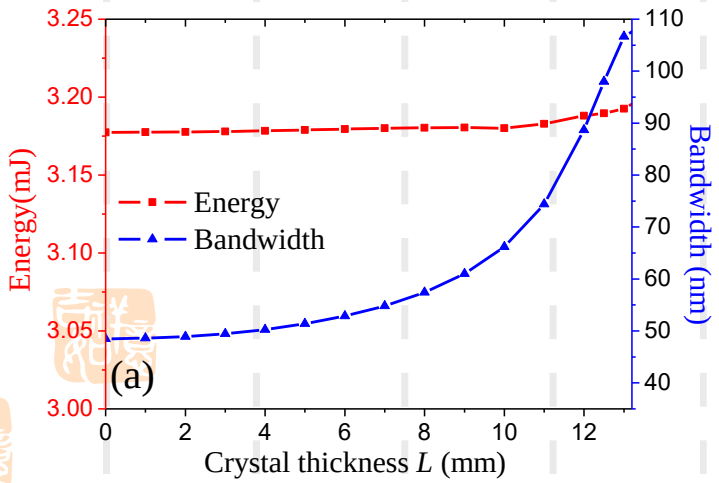
Polarization-dependent gain cross section

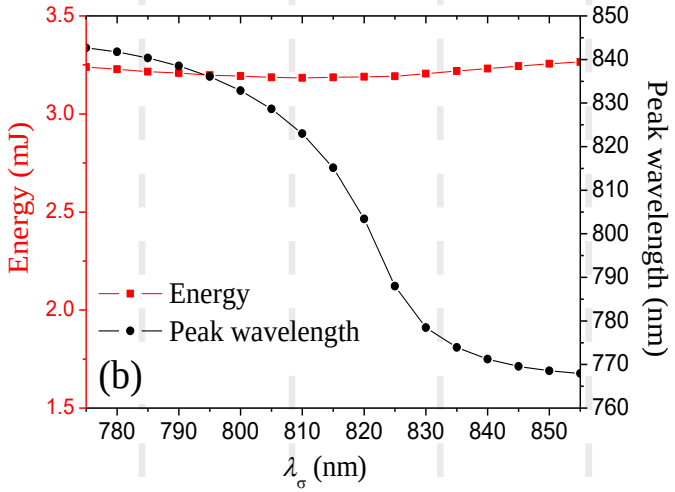
$$\sigma(\lambda) = \sigma_\pi(\lambda)\cos^2(\theta) + \sigma_\sigma(\lambda)\sin^2(\theta)$$

$$\cos^2(\theta):\ \sigma(\lambda) = \sigma_\pi(\lambda)$$
$$\sin^2(\theta):\ \sigma(\lambda) = \sigma_\sigma(\lambda)$$

$$\frac{\partial E_0(z,t)}{\partial z}=\frac{1}{2}\left\{\sigma(\omega_i(t))-i\frac{2[\omega_i(t)-\omega_a]}{\Delta\omega_a}\sigma(\omega_i(t))\right\}N(z,t)E_0(z,t)+i\beta''\frac{\partial^2 E_0(z,t)}{\partial t^2}-i\frac{\beta_2}{2}|E_0(z,t)|^2E_0(z,t)$$

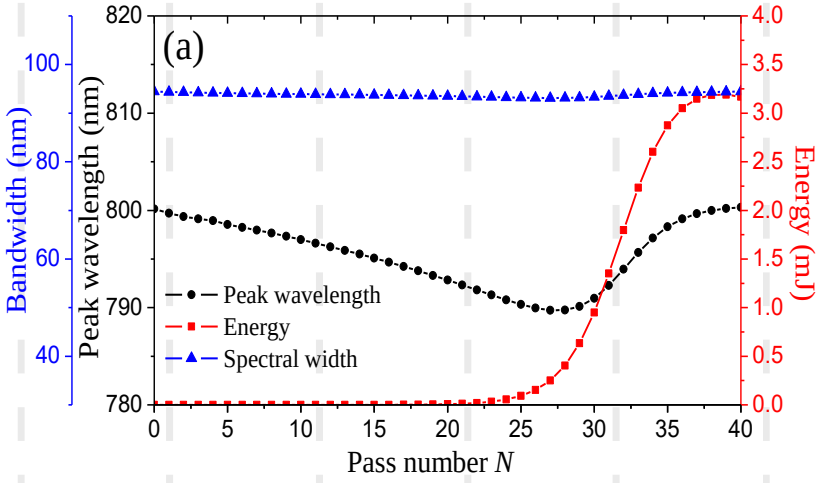
$$\frac{\partial N(z,t)}{\partial t}=-\frac{2^*}{h\omega_0}\sigma(\omega_i(t))N(z,t)\frac{\varepsilon c|E_0(z,t)|^2}{2}$$

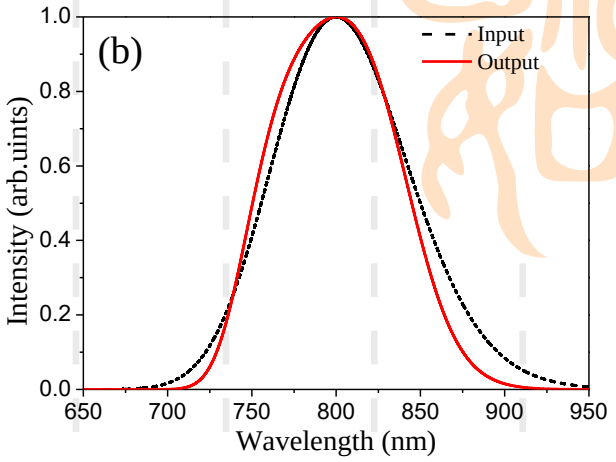




For a fixed λ_σ =816.65 nm (a), and For a fixed L (=11.8 mm) (b)

One can tune central wavelength or bandwidth of the amplifier with very stable output energy by changing λ_σ which can be realized by simply rotating the broadband half-wave plate or by changing the thickness of the ORD crystal.

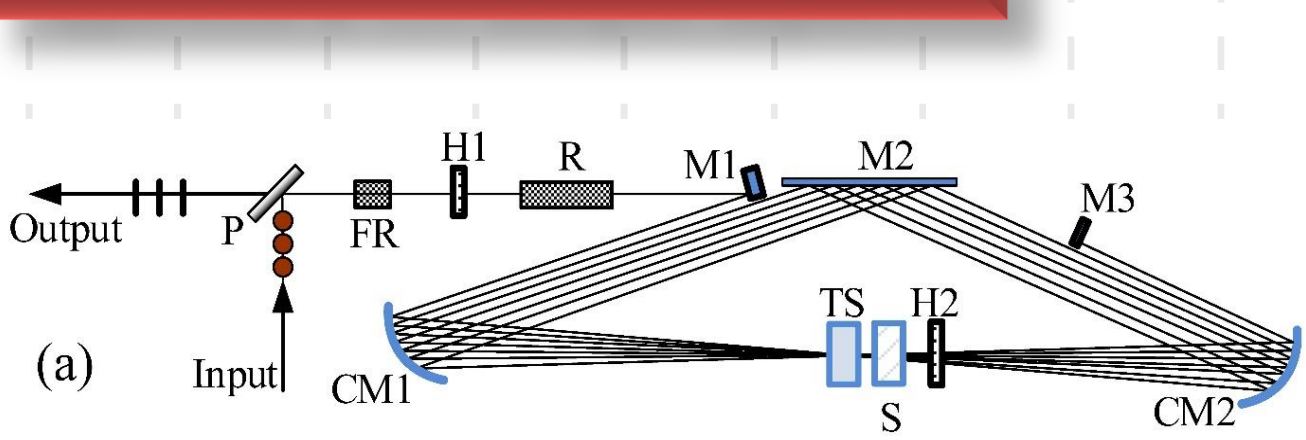


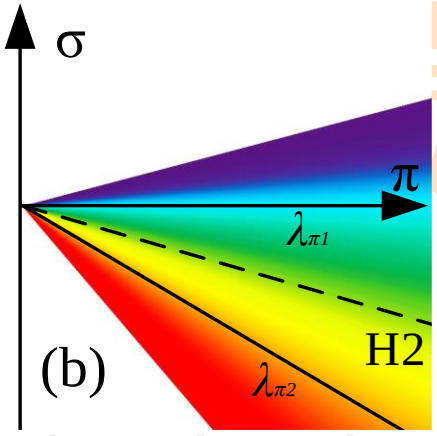


The output peak wavelength (black line), bandwidth (blue line) and pulse energy (red line) of the amplified pulse vs. pass number *N* with λ_σ=819.27 nm and *L*=12.27 mm (a), and corresponding input (black line) and output spectra (red line) (b).

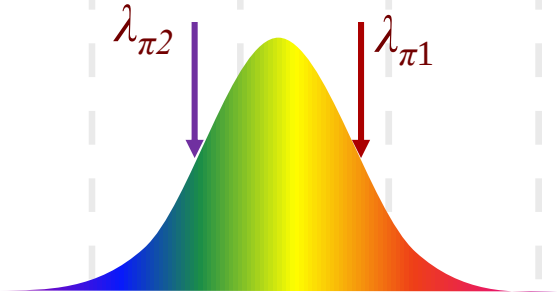
Proper ORD allows us to avoid both spectral narrowing and spectral shift in mJ-level saturated regenerative amplification.

Application in Ti:S multipass amplification



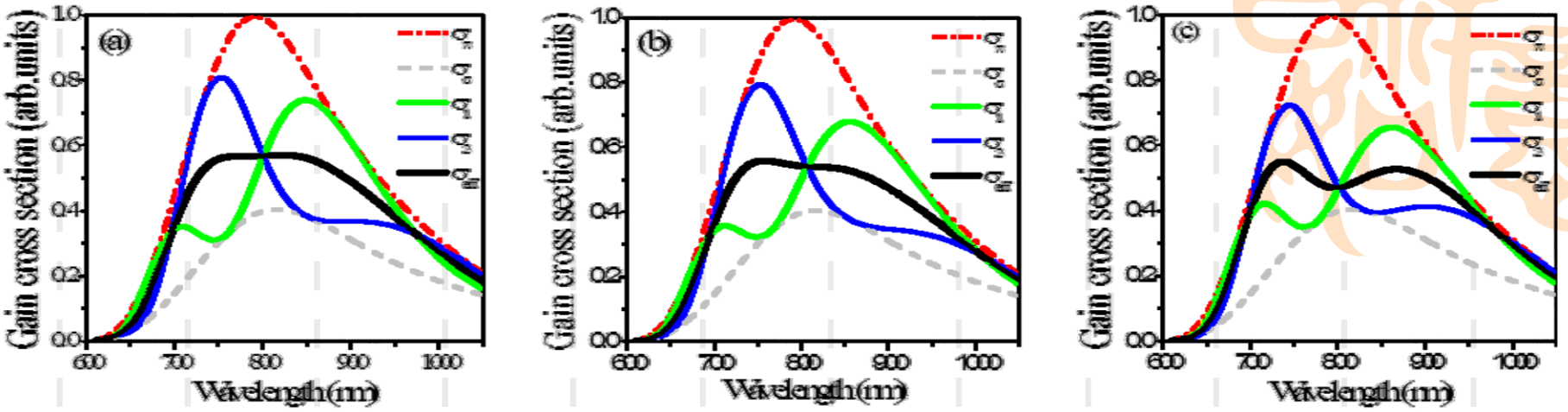


The π-polarized wavelength $\lambda_{\pi 1}$ for the odd-numbered amplification is different from $\lambda_{\pi 2}$ that for the even-numbered amplification.



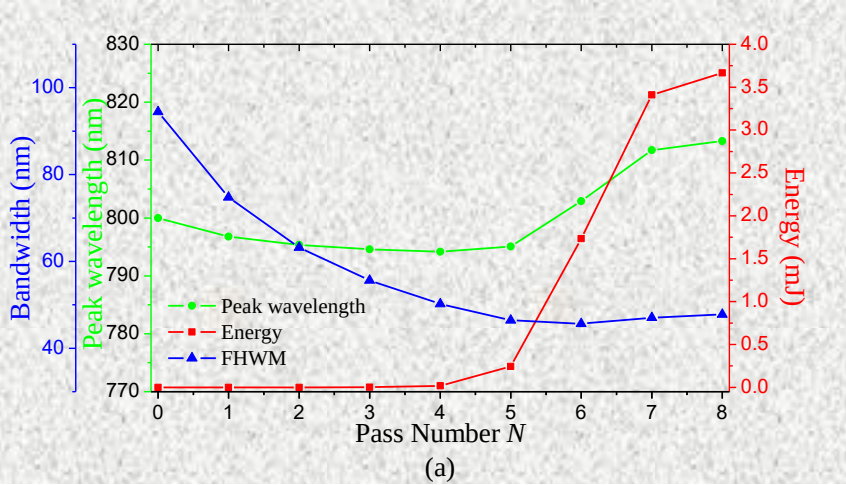
$\lambda_{\pi 1}$ and $\lambda_{\pi 2}$ are on the opposite sides relative to the gain peak wavelength.

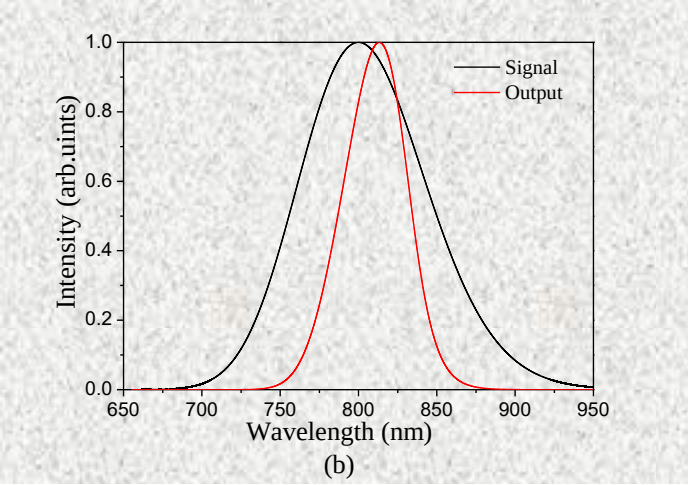
Optics and Lasers in Engineering, 78, 86–90(2016)



Gain cross section under different $\lambda_{\pi 1}$, $\lambda_{\pi 2}$ and L: (a) $\lambda_{\pi 1}$=900nm, $\lambda_{\pi 2}$=730nm L=23.5mm; (b) $\lambda_{\pi 1}$=926nm, $\lambda_{\pi 2}$=725nm L=21.6mm; (c) $\lambda_{\pi 1}$=930nm, $\lambda_{\pi 2}$=716nm, L=23mm.

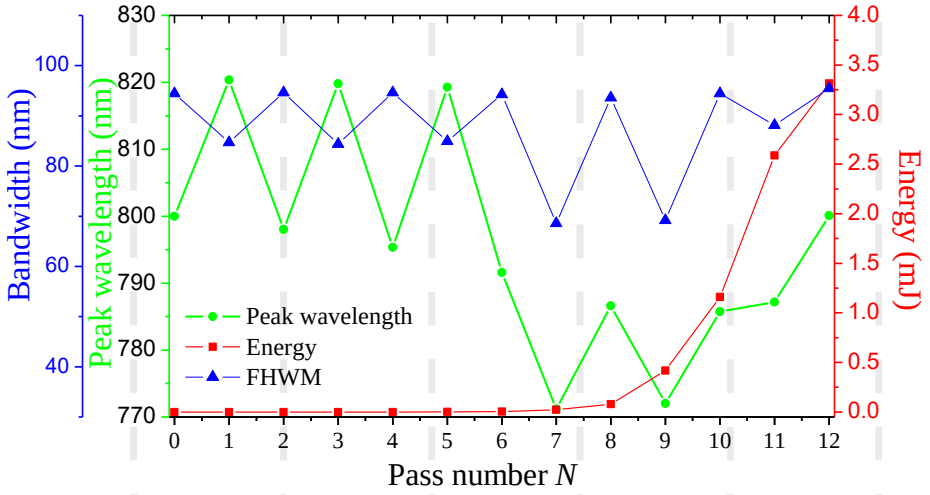
pump	Ti:sapphire	Seed pulse
Wavelength λ_p : 532 nm	Thickness: 10 mm	Peak wavelength: 800 nm
Total energy: 100 mJ	Absorption coefficient: 1.39 cm^{-1} at 532 nm	Initial energy: 0.4 nJ
Spot diameter: 1.8 mm	Peak of σ_π: 3.60×10^{-19} cm^2	Spot diameter: 0.66 mm
	Peak of σ_σ: 1.47×10^{-19} cm^2	Time envelope: Gaussian
	n_{SAL}: 2.5×10^{-16} cm^2/W	Spectral width: 94.5 nm (FWHM)
	β'': 57.25 fs^2/mm	Chirped pulse width: 600 ps (positive chirp)

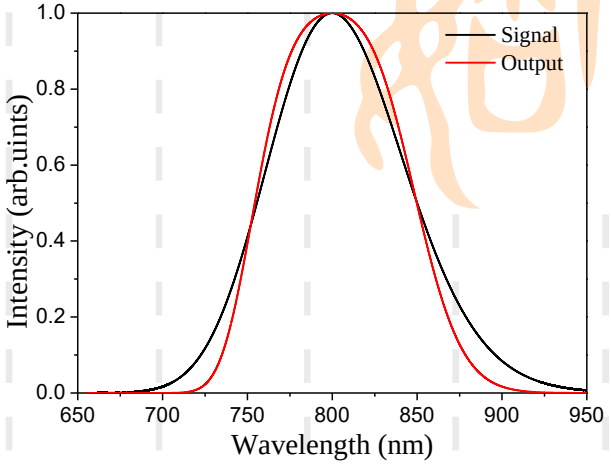




The evolution of the amplified pulse vs. pass number *N* basing on π-polarization setting but without ORD induced. (a) Bandwidth (blue line), peak wavelength (green line) and energy (red line) of amplified pulse, and (b) corresponding input (black line) and output (red line) spectra.

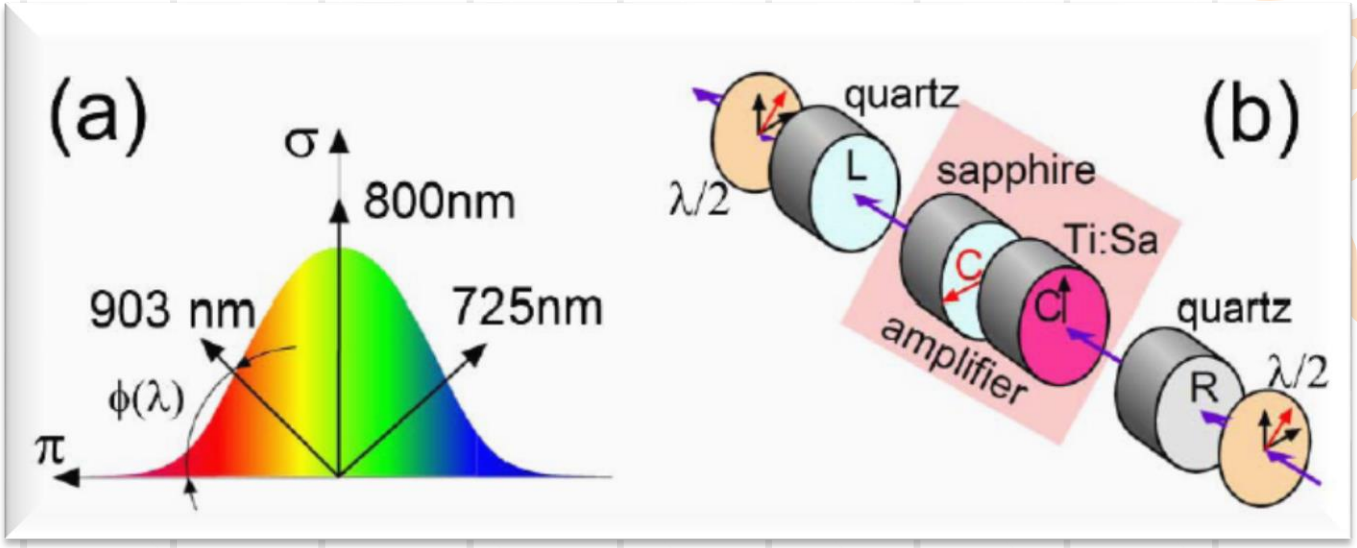
Without rotatory dispersion，obvious spectral-narrowing and red-shifting occur.





The evolution of the amplified pulse vs. pass number N as shown in figure 1(a) with $\lambda_{\pi 1}$=926 nm, $\lambda_{\pi 2}$=725 nm, L=21.6mm. (a) Bandwidth (blue line), peak wavelength (green line) and energy (red line) of amplified pulse, and (b) corresponding input (black line) and output (red line) spectra.

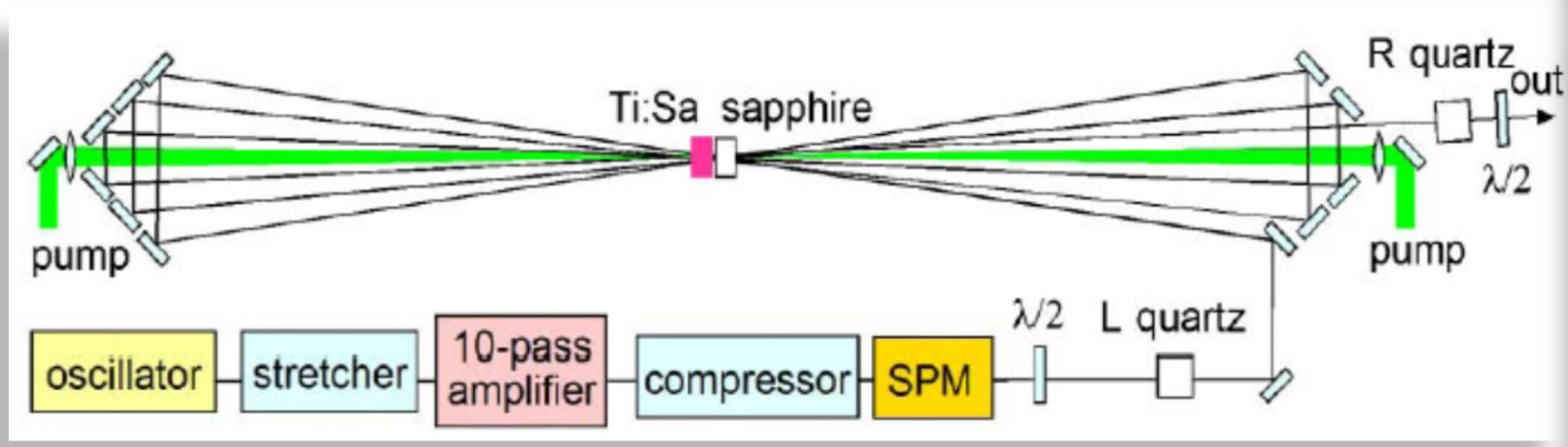
Proper rotatory dispersion and λ_{π}, spectral-narrowing and red-shifting can be avoided.

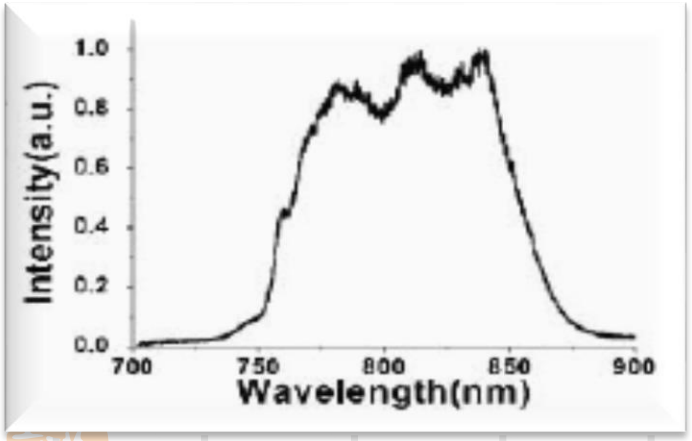


By setting proper rotatory dispersion and λ_π, scientists from Max-Born-Institut for Nonlinear Optics and Short Pulse Spectroscopy have experimentally obtained output bandwidth up to 85 nm with an optical gain of 200. They predicted this way may allow us to get few-cycle peta-watt optical pulses. A really encouraging prediction !

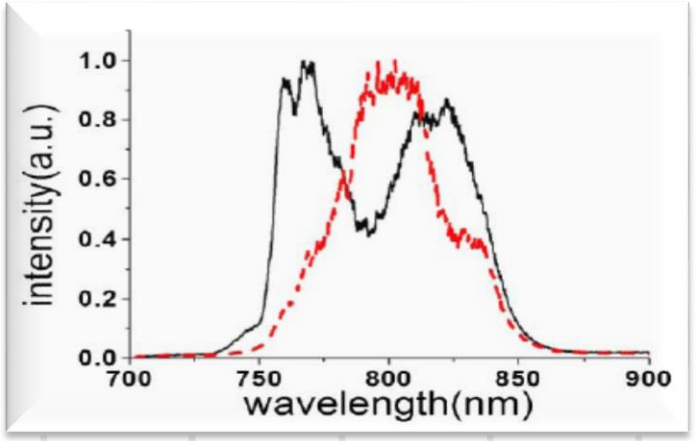
M. KALASHNIKOV group, Opt. Lett. 41, 25–28(2016)

Layout of multi-pass amplifier



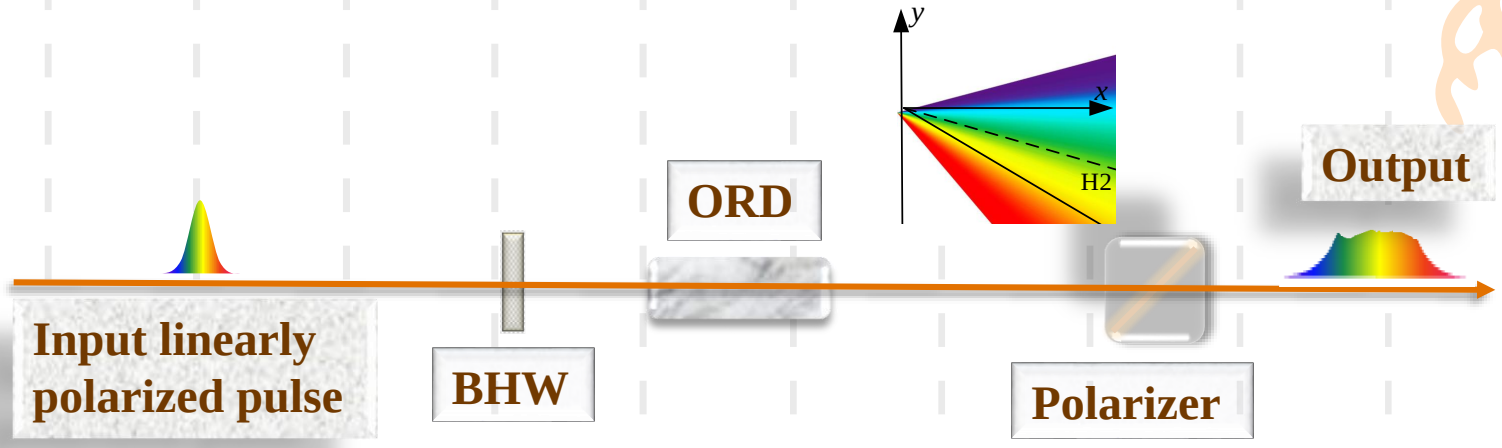


Seeded spectrum



Amplified spectra with (black) and without ORD: G=200

3. Application-2: pulse spectral shaping



Setup for spectral shaping

- Broadband half-wave plate: to rotate the polarization of all input spectral components
- Optical rotatory dispersion crystal: to produce the rotatory dispersion

$$\alpha(\lambda)=\eta(\lambda)L-\alpha_0,$$

$$\alpha_0=\alpha(\lambda_0)$$

$$\eta(\lambda)$$

Tunable band-pass filter

ORD
Wedge pair

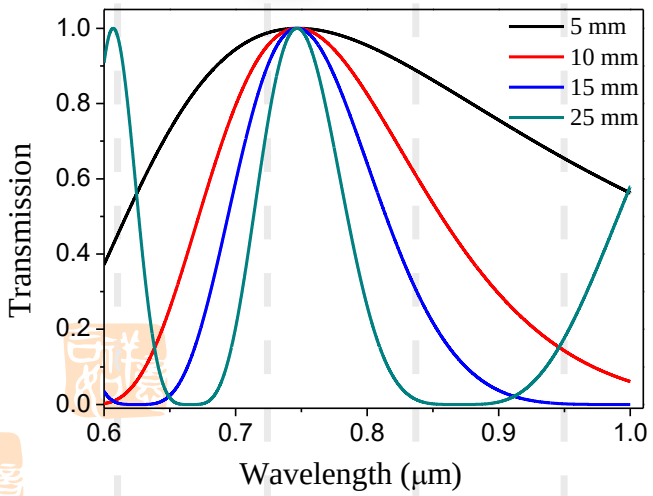


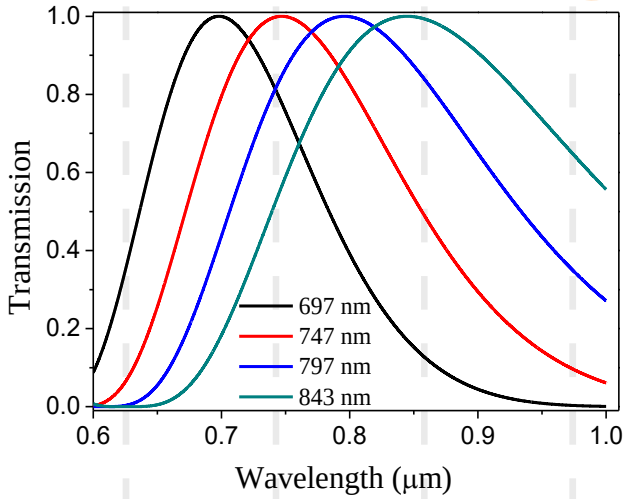
BHW



ORD







Bandwidth-tunable filter

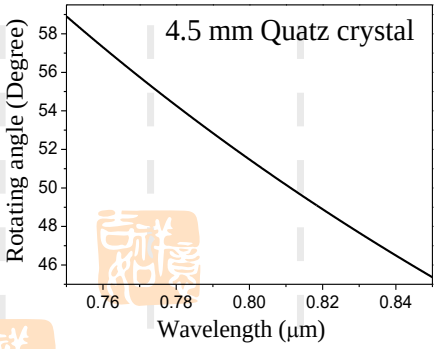
Central wavelength-tunable filter

Using Quartz as ORD crystal:

*** Different thickness→ Different transmission band;**

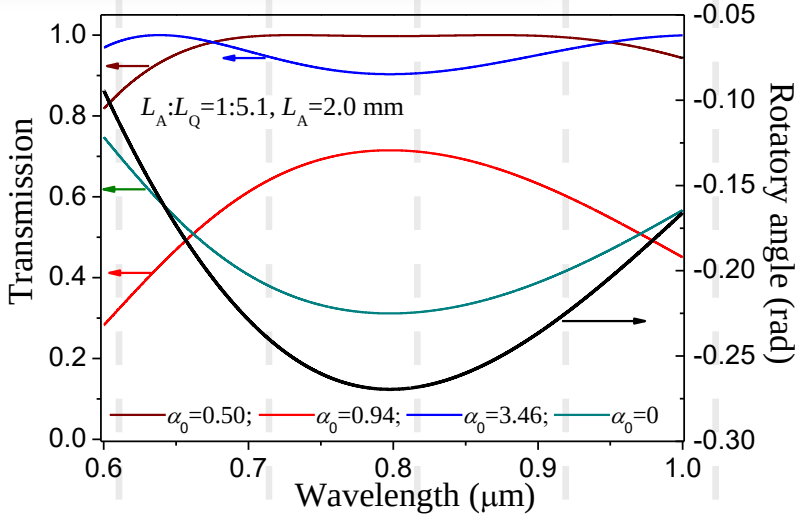
*** Tunable peak wavelength by changing λ_0.**

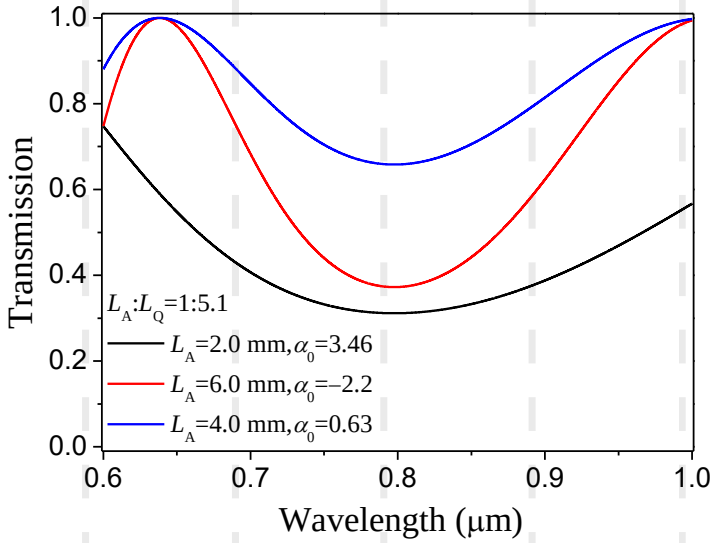
From visible to near infrared, the absolute value of rotation coefficient $\eta(\lambda)$ decreases with wavelength. However, this monotonous trend can be changed by using the combination of multiple ORD crystals.



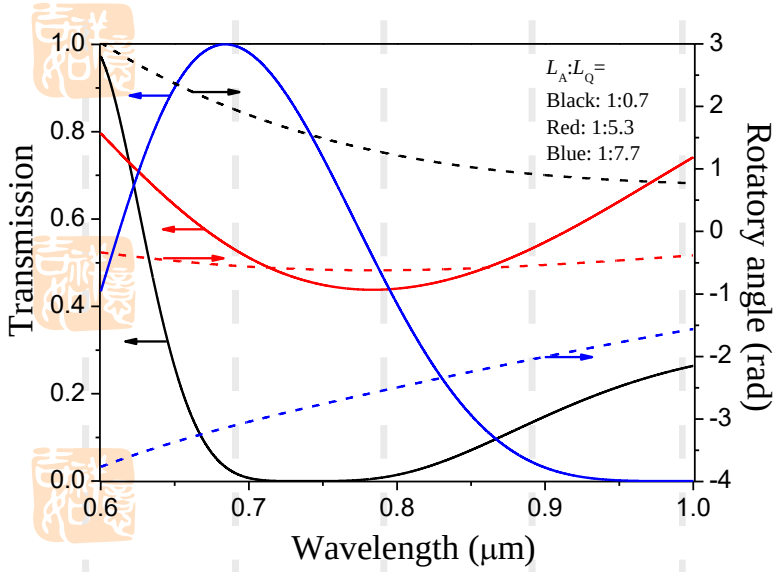


Parabolic rotatory dispersion profile: alter the transmission by rotating the BHW.





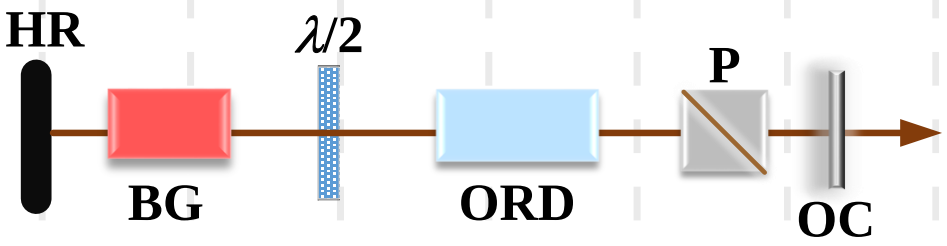
Alter the transmission by changing proportionally thicknesses of the crystals.



Alter the transmission by changing the ratio of the thicknesses of the crystals.

All spectral manipulations are of amplitude modulation.

4. Application-3: tunable laser

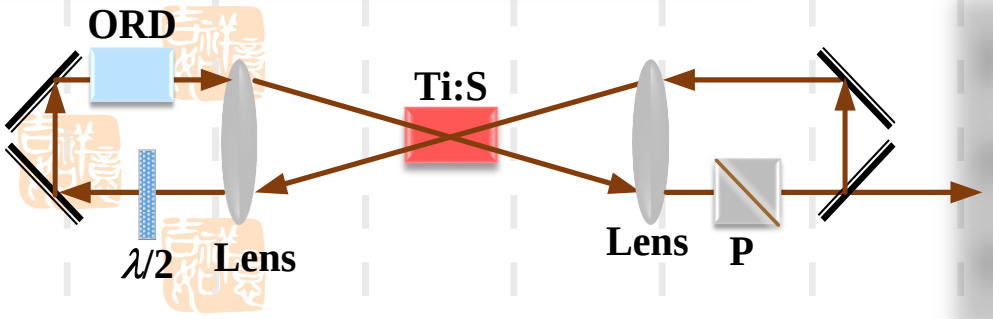


Apply the setup for spectral shaping into a laser cavity: tune the output wavelength

Spectral loss-encoding

$$Loss: S(\lambda) \propto \cos^2[\theta(\lambda)]$$

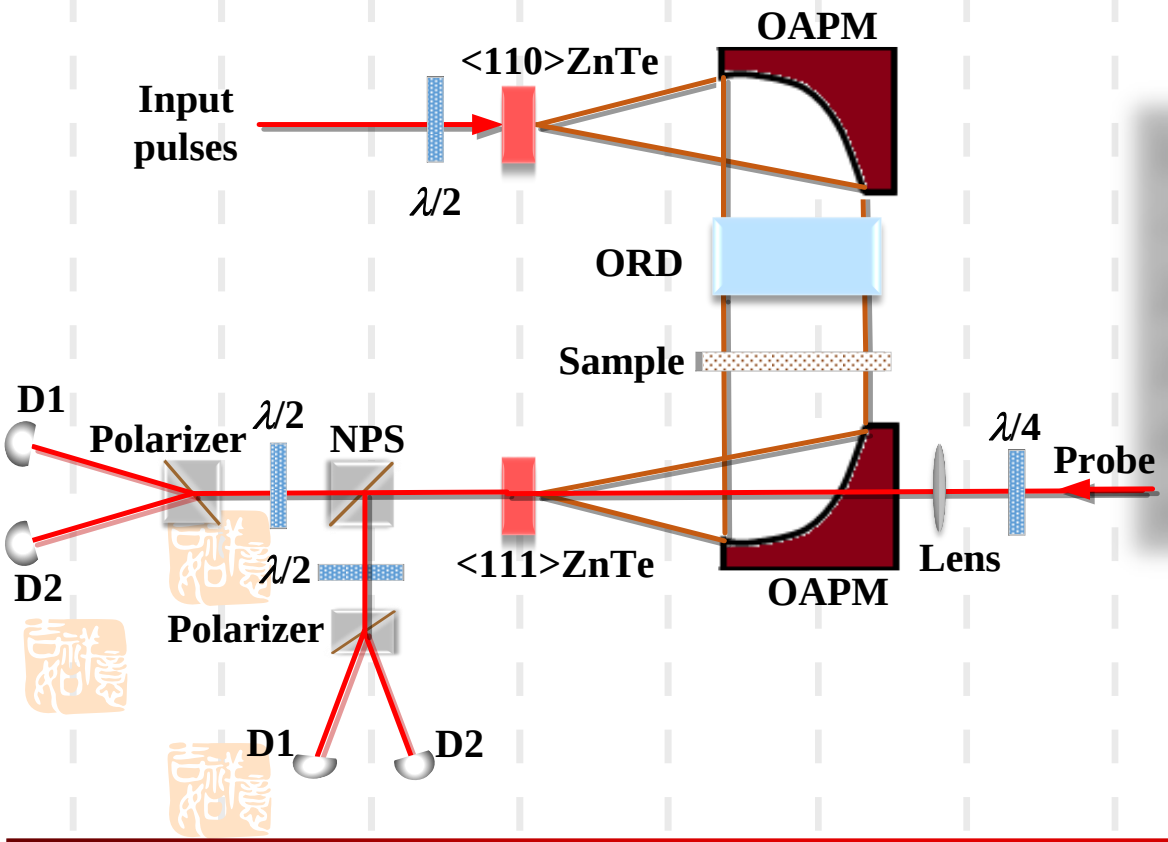
BG: Broadband gain medium



Flexible manipulation of the loss allow to control the tunable output easily.

Polarization-dependent gain: Spectral (loss+gain)-encoding

5. Terahertz polarization spectroscopy



Insert a ORD in THz FS -TDS and use a <111> ZnTe instead of <110> ZnTe for polarization-dependent transmission and absorption

Opt. Lett. 30, 2802(2005)

- **<111> cut ZnTe crystal allows for the detection of both components of THz electrical field at the same time;**
- **Rotatory dispersion crystal allows different spectral components of THz pulse have their own polarization directions.**



Thanks for your attentions