Femtosecond Pulse Shaping for Planar Interconnection System

Hua Zou
College of Science, Hohai University, Nanjing Jiangsu
210098, China

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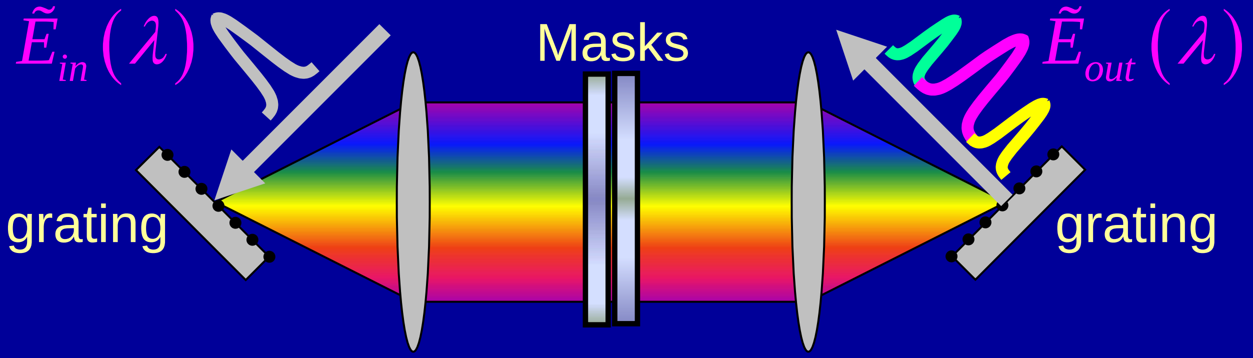
Overview

- Methods of pulse shaping
    - Fourier synthesis
    - Spatial-light modulators
    - Acousto-optic modulators
    - Deformable mirror
    - Moving mirror
    - Spectral holography

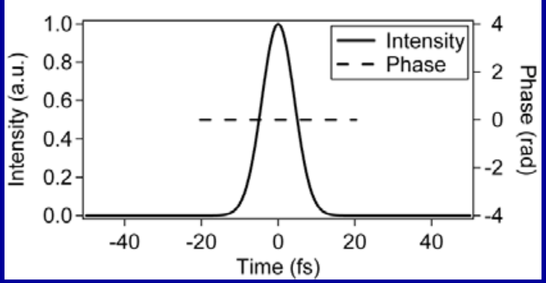
- Phase-only pulse shaping
    - Genetic algorithms
    - Simulated annealing

Why pulse-shape?

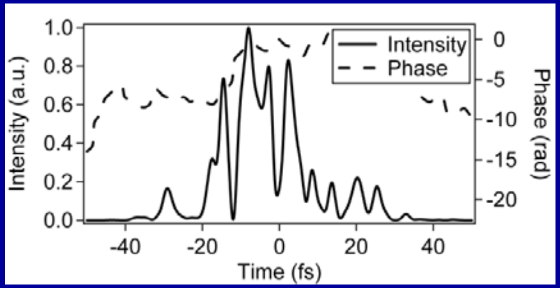


- To compress pulses with complex phase
- To generate pulses that control chemical reactions or other phenomena
- To generate trains of pulses for telecommunications
- To precompensate for distortions that occur in dispersive media

What do we really mean by pulse shaping?



Pulse Shaper



Experiment

Pulse	Results
1	45
2	37
3	12
4	80

Tailoring a pulse shape in a specific controlled manner.

By changing the pulse shape we can alter the results of an experiment

How do we modulate an ultrashort pulse?

We could try to modulate the pulse directly in time.

$$E_{out}(t) = h(t)E_{in}(t)$$

Unfortunately, modulators are too slow.

Alternatively, we can modulate the spectrum.

$$\tilde{E}_{out}(\omega) = H(\omega)\tilde{E}_{in}(\omega)$$

So all we have to do is to frequency-disperse the pulse in space and modulate the spectrum and spectral phase by creating a spatially varying transmission and phase delay.

Theory of Femtosecond Pulse Shaping

- In the time domain

$$e_{out}(t) = e_{in}(t) * h(t) = \int dt' e_{in}(t') h(t - t')$$

- In the frequency domain

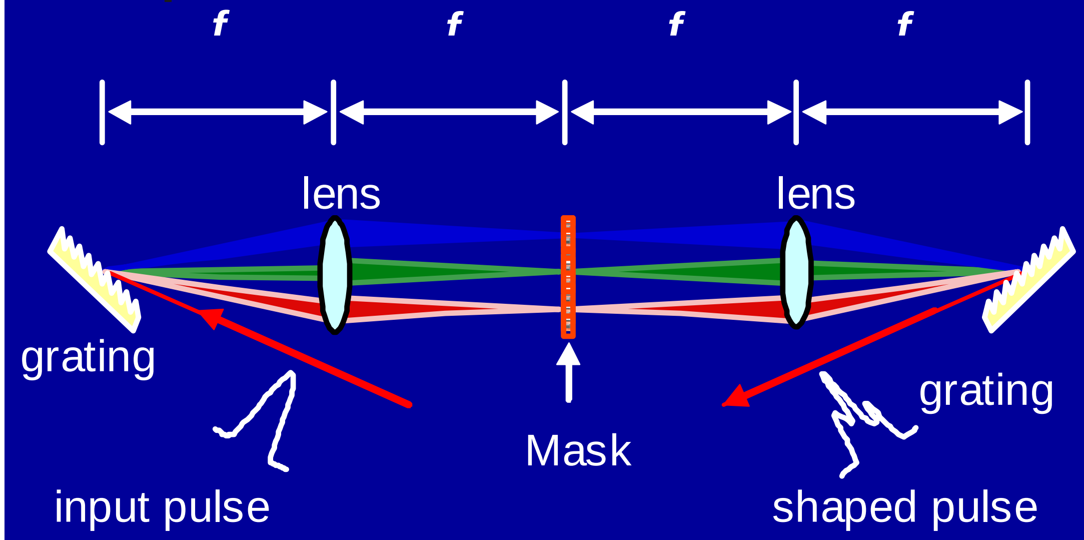
$$E_{out}(\omega) = E_{in}(\omega) H(\omega)$$

- $$H(\omega) = \int dt h(t) e^{-i\omega t}$$

- $$h(t) = \frac{1}{2\pi} \int d\omega H(\omega) e^{i\omega t}$$

Therefore, due to the Fourier transform relations, generation of a desired output waveform can be accomplished by implementing a filter with the required frequency response.

Traditional Apparatus for Femtosecond Pulse Shaping



Apparatus for femtosecond pulse shaping for time-to-space conversion of ultrafast optical waveforms.

How it works:

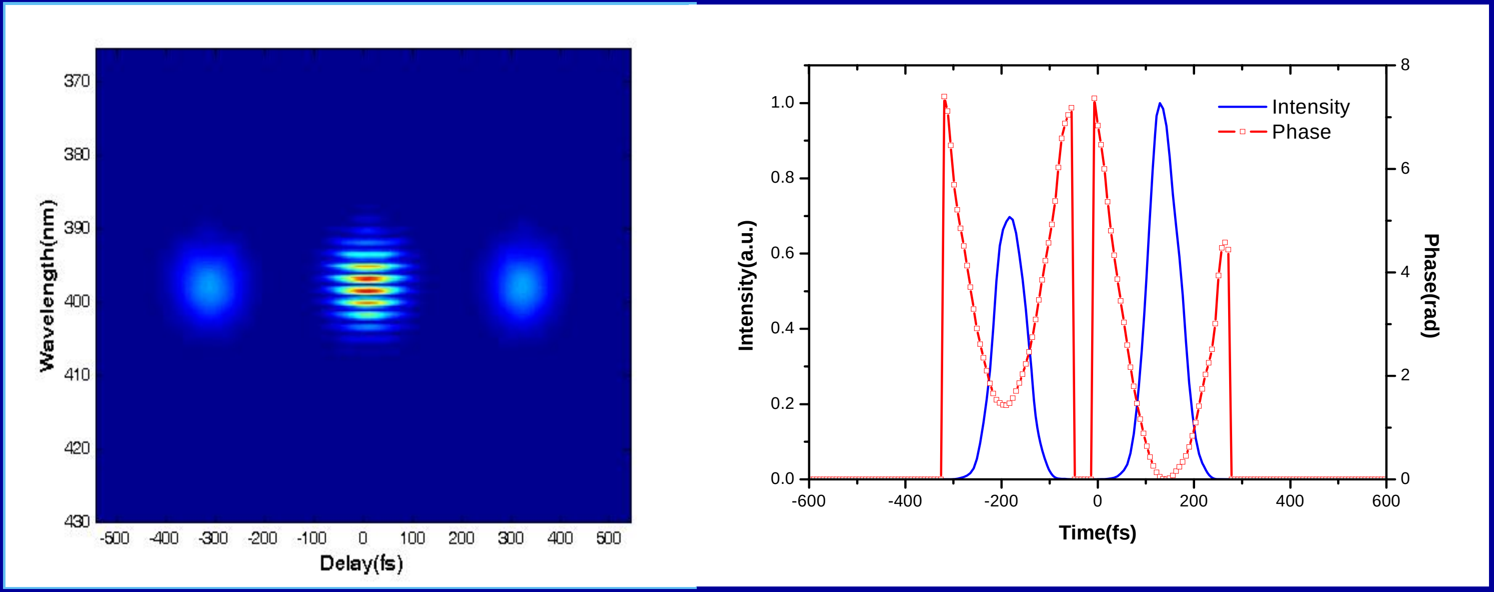
The grating disperses the light, mapping color onto angle.

The first lens maps angle (hence wavelength) to position.

The second lens and grating undo the spatio-temporal distortions.

The trick is to place a mask in the Fourier transform plane.

Pulse Shaping with Dammann Grating



Experimental FROG trace of pulse shaping for two pulses. Intensity and phase of the pulse retrieved from the FROG trace

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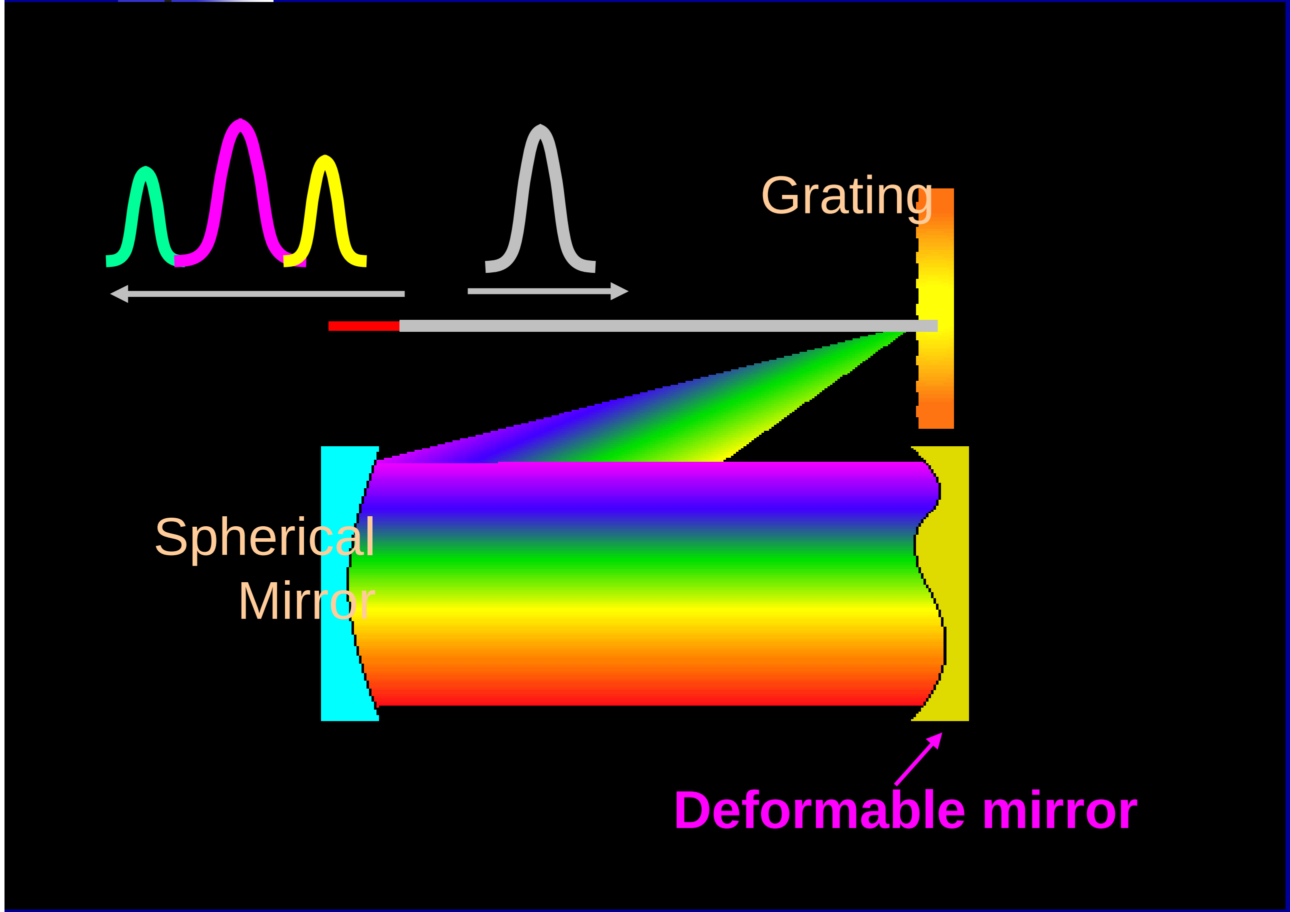
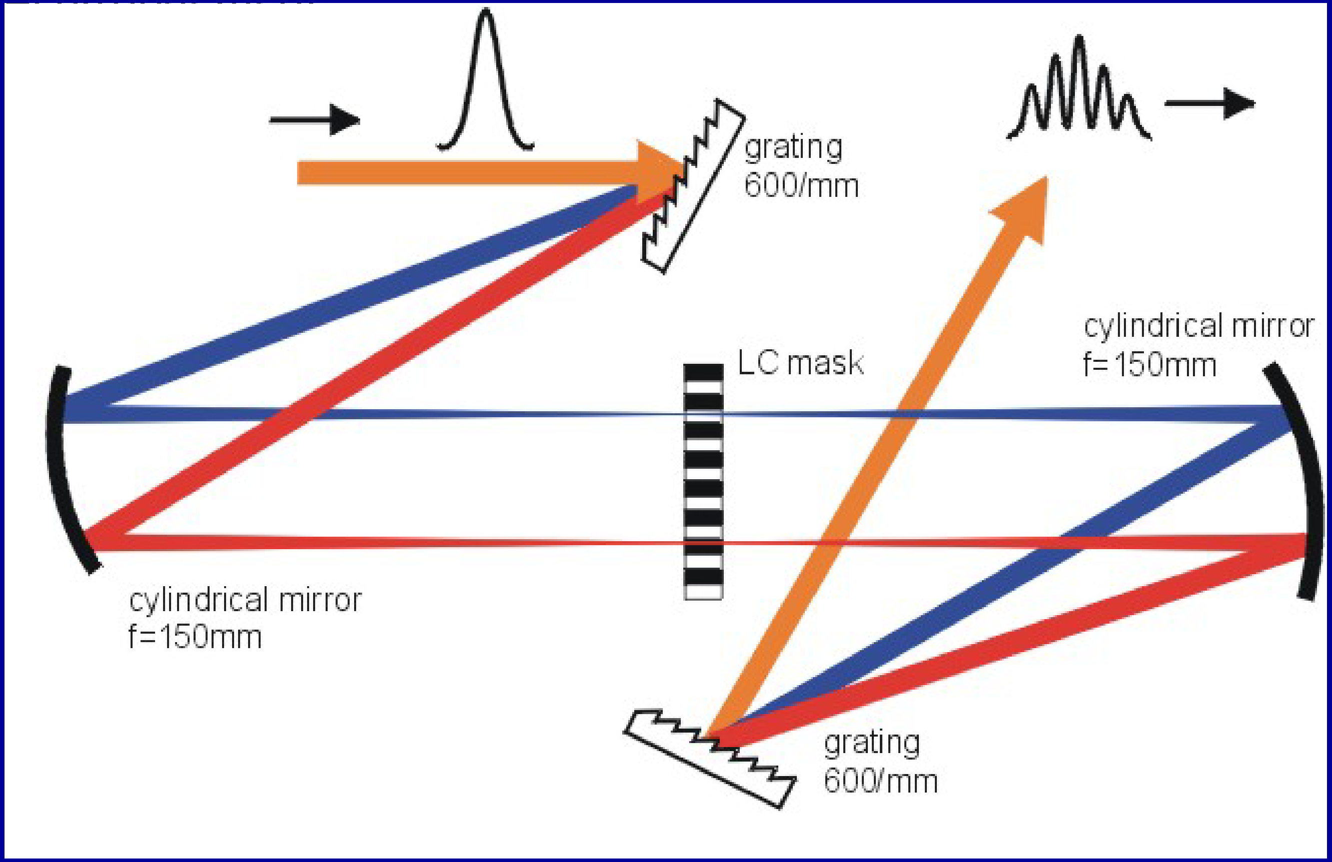
Deformable-Mirror folded Pulse-Shaper

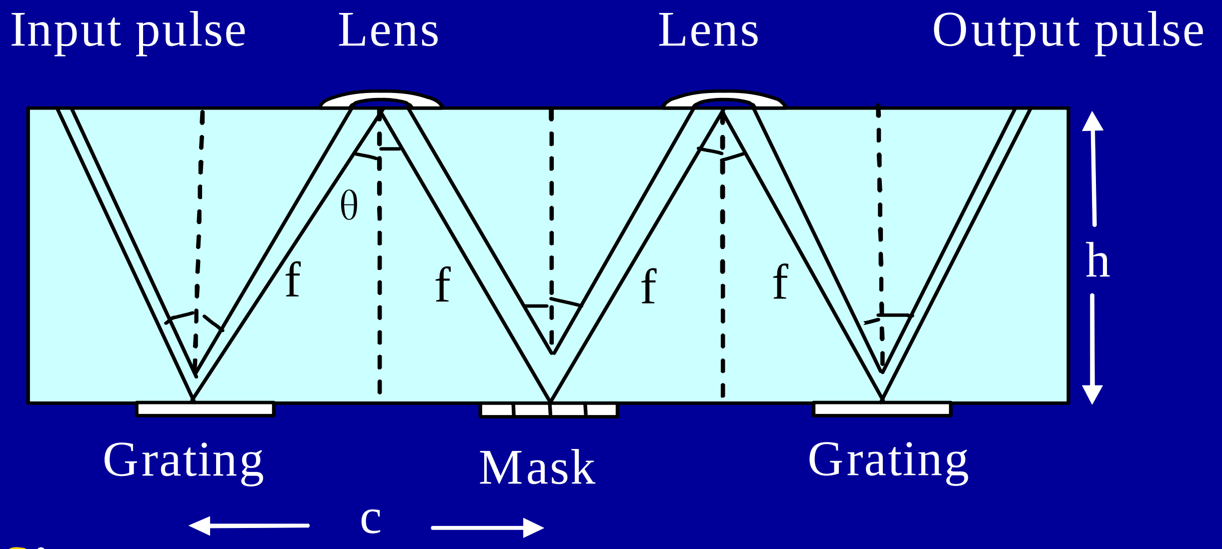


This modulates the phase but not the amplitude.

Liquid-crystal spatial light modulators



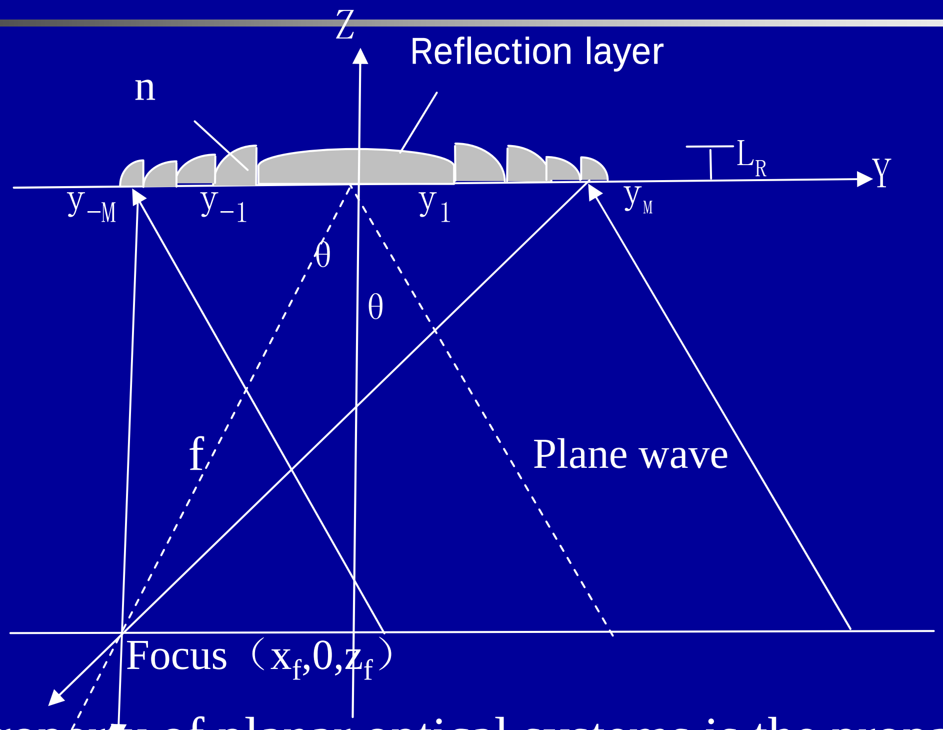
Apparatus of Femtosecond Pulse Shaping Based on Planar Optics



How it works:

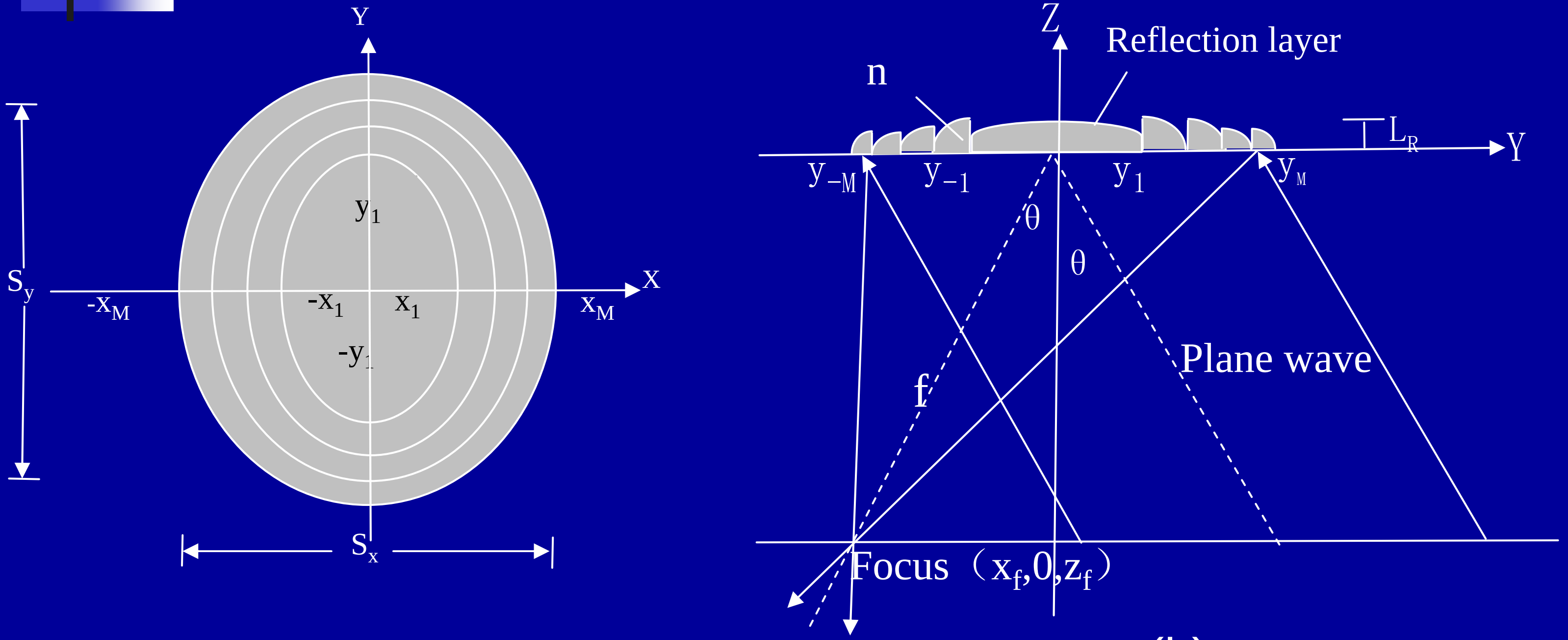
- The light signal travels within the substrate from one element to the next one, along a folded path reflected at the surfaces of the substrate.
- Spatially patterned masks are inserted midway between the lenses at the point where the optical spectral components experience maximal spatial separation.
- The second lens and grating reassemble the various spectral components into a single collimated beam. When patterned mask is present, the output pulse shape is given by the Fourier transform of the pattern modified by the masks onto the spectrum.

Lens Structure and Design



One inherent property of planar optical systems is the propagation of light signals along an oblique optical axis. Compared with conventional optical systems with Cartesian symmetry, aberrations occur that are not present in systems, in which a well-established theory of components and systems can be used, the design of planar optics requires more theoretical efforts.

Lens Structure and Design

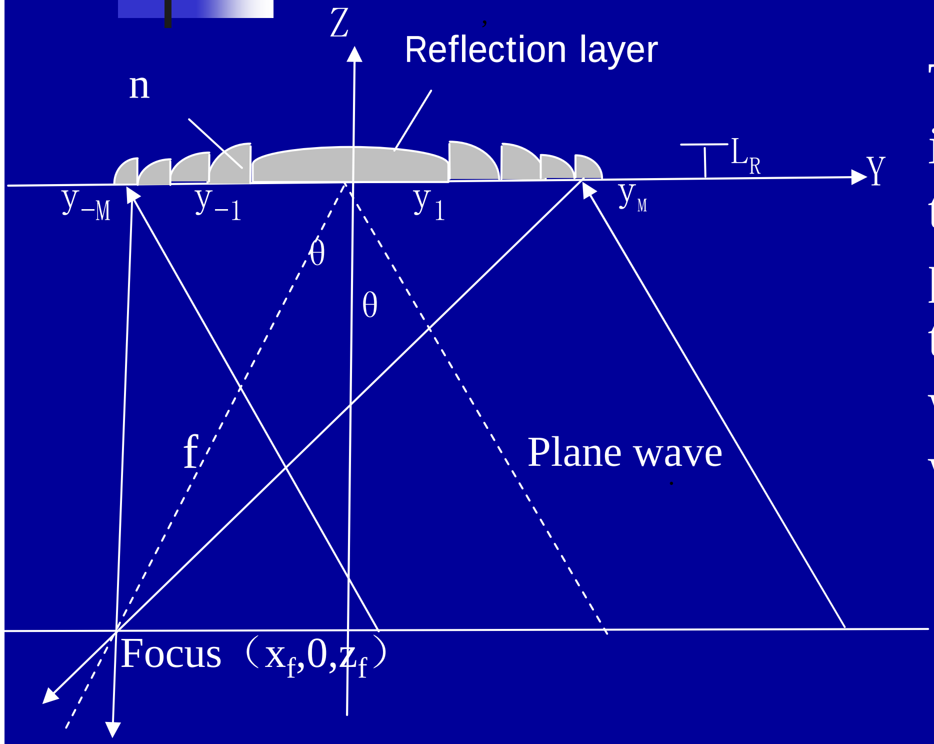


(a) (b)

Structure of the reflection diffractive lens for oblique incidence. (a) Plane figure, (b) Cross section.

The structure of the proposed reflection diffractive lens without chromatic aberration for oblique incidence.

Lens Structure and Design



Theory of lens design is the phase shift with integer π, namely, the phase difference in the X-Y plane between a plane wave propagating with an oblique angle θ from the Z axis and a spherical wave converging with optical axis symmetric to the incident wave axis is integer π, is written by

$$\Phi(x,y)=\frac{2\pi n'}{\lambda}\{[(x+x_f)^2+y^2+z_f^2]^{\frac{1}{2}}-f+x\sin\theta\}$$

where $x_f=-f\sin\theta$ $z_f=-f\cos\theta$

Lens Structure and Design

The above equation changes as:

$$\Phi(x,y)=\frac{2\pi}{\lambda}\{[(x-f\sin\theta)^2+y^2+(f\cos\theta)^2]^{\frac{1}{2}}-f+x\sin\theta\}$$

The phase shift Φ_F of a diffractive lens is given by dividing Φ with a modulus 2 π :

$$\Phi_F=\Phi(x,y)-2m\pi$$

Then, let us consider the grating patterns that provide the zone boundaries of the lens. Let

$$\Phi(x,y)=\frac{2\pi}{\lambda}\{[(x-f\sin\theta)^2+y^2+f\cos\theta^2]^{\frac{1}{2}}-f+x\sin\theta\}-2m\pi=0$$

Lens Structure and Design

We can obtain:

$$\frac{x^2}{(m\lambda/\cos\theta)^2+2m\lambda f}+\frac{(y-y_{cm})^2\cos^2\theta}{(m\lambda/\cos\theta)^2+2m\lambda f}=1$$

$$y_{cm}=-m\lambda tg\theta/\cos\theta$$

We can conclude clearly that the contour line of this lens is an ellipse with a major axis of Y where the center position is $(0, y_{cm})$.

Advantages

- First, the compact structure, our apparatus is smaller than the common femtosecond pulse shaper because of the folded stucture.
- Second, the better stability, the every element is located at the close substrate, which has the better stability relative to the mechanical and hot effect, and the light propagates without outside environment interference such as the ventilation;
- Finally, the high efficiency, the apparatus has high efficiency because the input waveform is only focused with the reflective lens.

Summary

- We introduce the femtosecond pulse shaping technique.
- We gave the theory of femtosecond pulse shaping based on planar optics and then proposed the design of planar optics lens firstly .
- The special aspect of our results is the use of planar optics structure instead of the more conventional transmission type structure, as they would offer improved properties. Our investigation also showed that an optimized design can be obtained for a specific combination of femtosecond pulse shaping and planar optics system.

Thank you!