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Mid-IR Dispersive mirrors

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Summary

Dispersive mirrors in Mid-IR (1 – 6 μm) range could finally substantially aid the combination of various bulk materials, such as semiconductors (Si, Ge, GaAs) and dielectrics (fluorides, sapphire, YAG) as the straightforward means to compensate dispersion and compress ultrafast mid-IR laser pulses.

The problem

Optical properties of most materials in the mid-IR spectral range limit their applications for broadband optics. So far, dispersion management in this range was achieved by combining transmissive materials with opposite signs of group velocity dispersion, for example combining Si with CaF_2 or BaF_2 . However, the availability of materials transparent in mid-IR spectral range is limited due to the presence of strong absorption bands. In addition, it can be difficult to find the right material combination to compensate precisely the complex phase characteristic acquired by the laser in the long optical path from the generation to the application. Semiconductors and dielectrics have opposite signs of GVD, which opens up a straightforward route to adjust the chirp. However, the specific TOD transferred to the pulse by material insertion is exclusively positive, which heavily limits the efficiency of recompression in the sub-3 cycle regime. Therefore, gaining control over the dispersion up to the 3rd order by specially designed dispersive optics plays a key role here.

Application field

The general field of research is attosecond/strong field physics where people like to investigate interactions of light with matter (atoms, molecules, nanostructures, solid state systems). The ponderomotive/quiver energy of free electrons scales as the square of the wavelength $U_p \sim \lambda^2$, which is why it is attractive to shift the wavelength of the lasers, traditionally operated at NIR, to the mid-IR. With longer wavelengths, electrons can be accelerated to much higher kinetic energies, which in turn allows to generate higher energy secondary photons in the XUV/X-ray range through high-harmonic generation (HHG).

Therefore, mid-infrared light sources are used for atomic physics experiments and HHG to investigate ultrafast processes at atomic time and nanometer spatial scales. HHG-sources are also mentioned as candidates for medical applications like coherent diffraction imaging in the water window. Such sources proved to be suitable also to quantify carrier envelope phase (CEP) variations of few cycle IR pulses on target.

Solution and benefits

Broadband dispersive mirrors for mid-IR range can reduce, or even completely eliminate, the need to use combinations of various materials to compensate dispersion and finally recompress broadband pulses close to Fourier limit duration in the sub-2 cycles regime. Ideally, such dispersive mirrors should be able to exactly compensate the dispersion that laser pulses acquire on their way from the source to the target. In this way, shorter pulse durations and higher peak intensities could be made available to the user.

Dispersive mirror

For this purpose, dispersive mirrors were manufactured by OPTOMAN. A multilayer was deposited by ion beam sputtering technology. The coating consists of 25 alternating layers, with total thickness of 7.4 μm . Special time control strategy was used for precise termination of layers because *in-situ* optical monitoring in MIR range is very complicated. The produced mirror exhibits average reflectance of $R > 98\%$ over the 2150-3700 nm wavelength range and $0\text{-}25^\circ$ angle of incidence for *p* polarization. As targeted in the problem description, the key feature of this mirror is its GDD value that is gradually increasing from -300 fs^2 at 2150 nm to 300 fs^2 at 3750 nm. By using this mirror at two different angles (10° and 25°) GDD oscillations can be somewhat suppressed, leading to smoother spectral phase response. Theoretical reflectance and GDD curves of the mirror are depicted in Fig. 1.

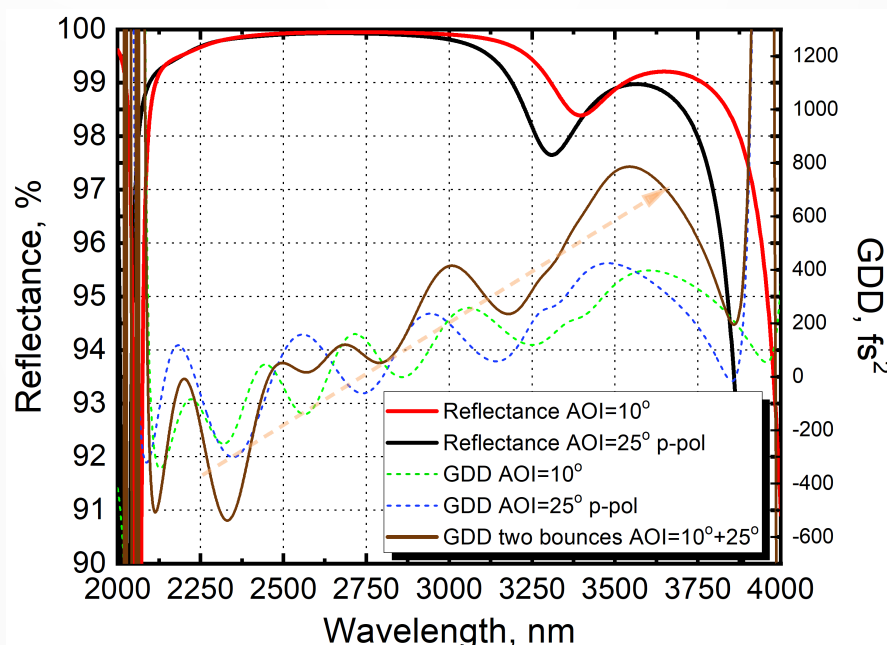


Fig. 1. Theoretical reflectance and GDD curves at 10° and 25° AOI.

Since dispersive mirrors are extremely sensitive to manufacturing errors, characterization of spectral phase shift was performed by Spectrally Resolved Interferometry (SRI) technique to quantify the actual GD performance of the mirrors and validate the designed phase curves. Mirrors were tested with a Mach-Zehnder interferometer setup in 2860-3480 nm wavelength range. The comparison between theoretically calculated and measured group delay curves is shown in Fig. 2. The SRI measurements show good agreement between calculated and measured GD values at both 10° and 25° angles.

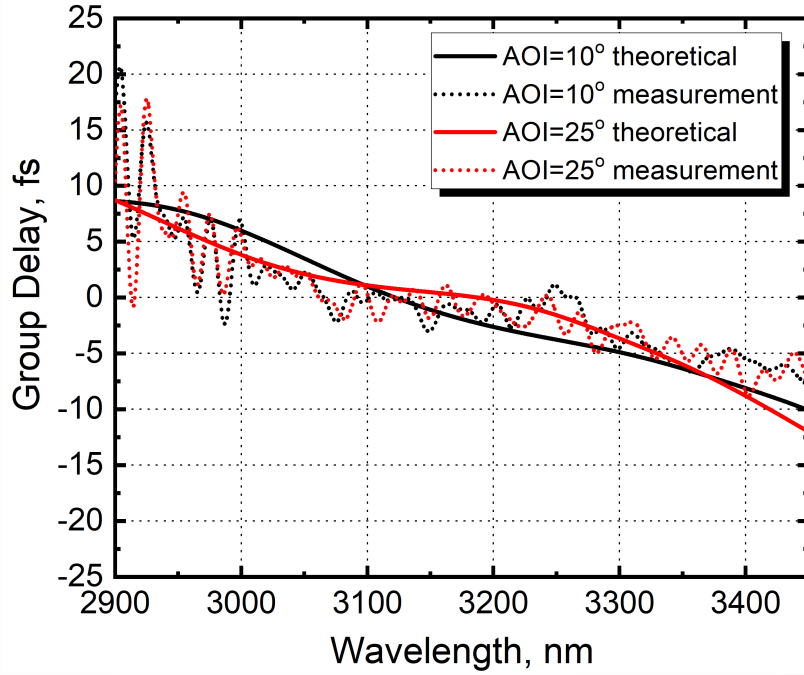


Fig. 2. Calculated and measured GD curves at 10° and 25° AOI

Finally, pulse compression efficiency of these mirrors was tested with spectrally broadened mid-IR pulses at **ELI-ALPS**. Laser pulses with 48 fs duration at 3100 nm central wavelength were focused into a spectral broadening unit consisting of BaF₂ and Si windows positioned along the beam waist. The pulse spectrum after the broadening unit (Fig. 3) supports 18 fs Fourier transform limited (FTL) duration and has positive chirp. Recompression performed with the combination of bulk CaF₂ and the dispersive mirrors, testing several configurations. Recompression was to 19 fs FWHM (1.9 cycles @ 3 μm) was successfully achieved by inserting 5 mm CaF₂ together with 3 reflections on the dispersive mirrors with angle of incidences of 10-25-25 degrees. Fig. 4 shows FROG traces, and retrieved time and spectrum intensities of the recompressed pulse

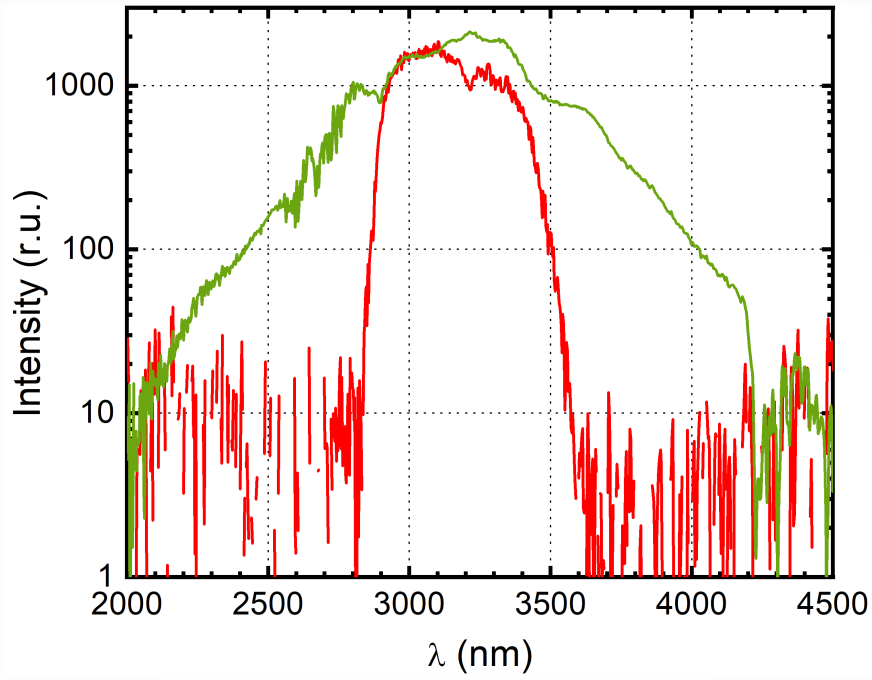


Fig 3. Initial (red) and broadened (green) spectral intensity.
(Measurement data belongs to ELI-ALPS)

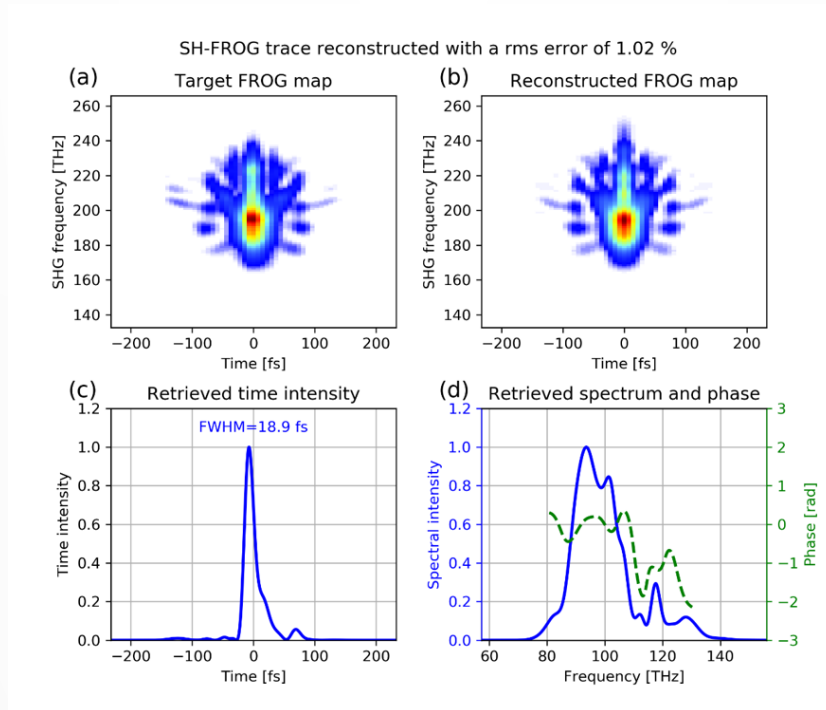


Fig. 4. Measured (a) and reconstructed (b) SH-FROG traces; reconstructed temporal intensity profile (c) and spectrum (solid line) with spectral phase (dashed line) (d).

About the company

OPTOMAN manufactures application-optimized and customized IBS-coated laser components in 200 – 6000 nm range and is one of the first companies worldwide to offer dispersive and broadband low GDD mirrors made for 2 – 6 μm with IBS technology.

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