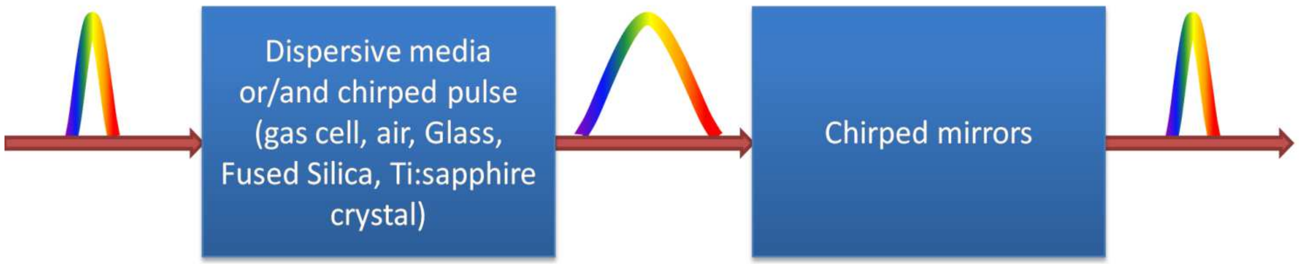
Nonlinear Optical Coatings at High Intensities

T. Amotchkina, M. Trubetskov, K. Fritsch, O. Pronin, F. Krausz, and V. Pervak

OCLA Symposium, 12.04.2017

Motivation

- Coatings for laser applications: dispersive mirrors, beamsplitters, input and output couplers



All calculations of spectral characteristics are carried out in the frame of the well-known linear theory

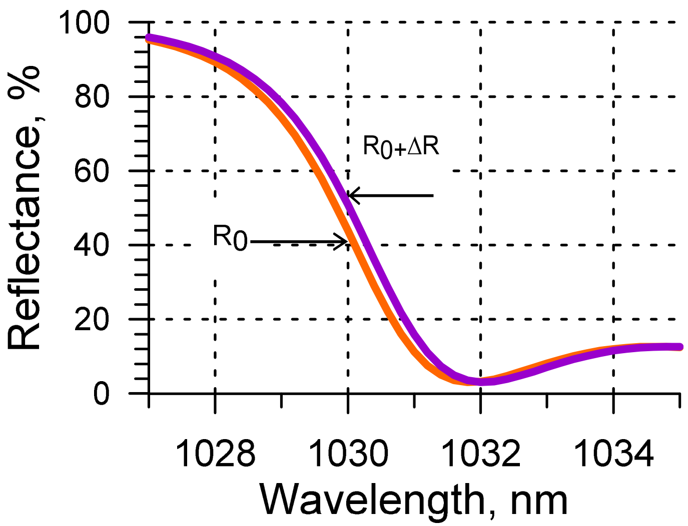
Motivation

What is going on with dielectric multilayer coatings at high intensities?

$$n = n_0 + n_2 I$$

- Study of the pre-damage behavior of dielectric multilayers;
- Revealing nonlinear effects at high intensities;
- Estimation of nonlinear additions of the refractive indices of coating layers
- A step forward to designing optical coatings with predictable nonlinear properties

Motivation



$$n = n_0 + n_2 I \quad \Rightarrow \quad R = R_0 + \Delta R$$

ΔR - modulation depth

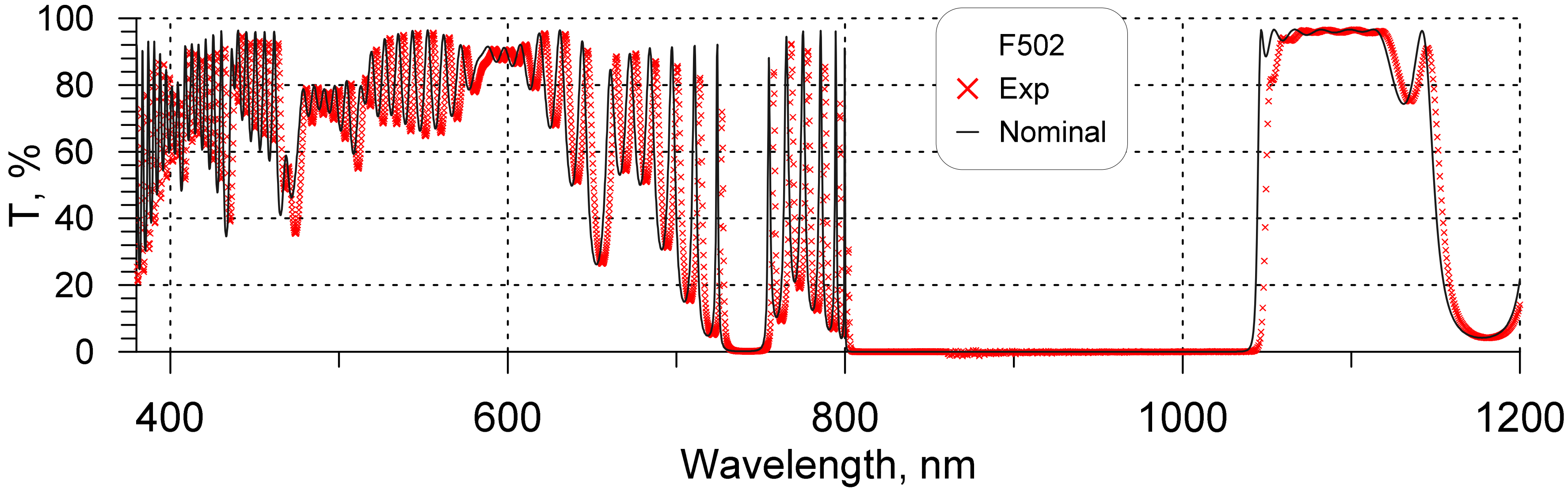
- Edge Filter with an extremely steep spectral reflectance in the vicinity of

$$\lambda = 1030 \text{ nm}$$

- High sensitivity to any refractive index variation;
- High sensitivity to the AOI variation

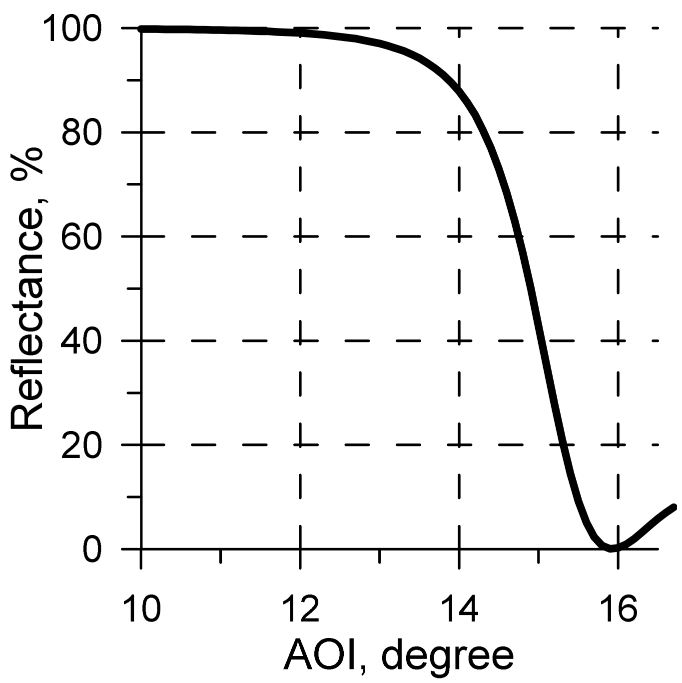
Production of experimental samples

- Layer Materials: Nb_2O_5/SiO_2
- Thickness 8.7 mkm, 69 layers
- Deposition: magnetron sputtering (Helios plant)
- Time monitoring



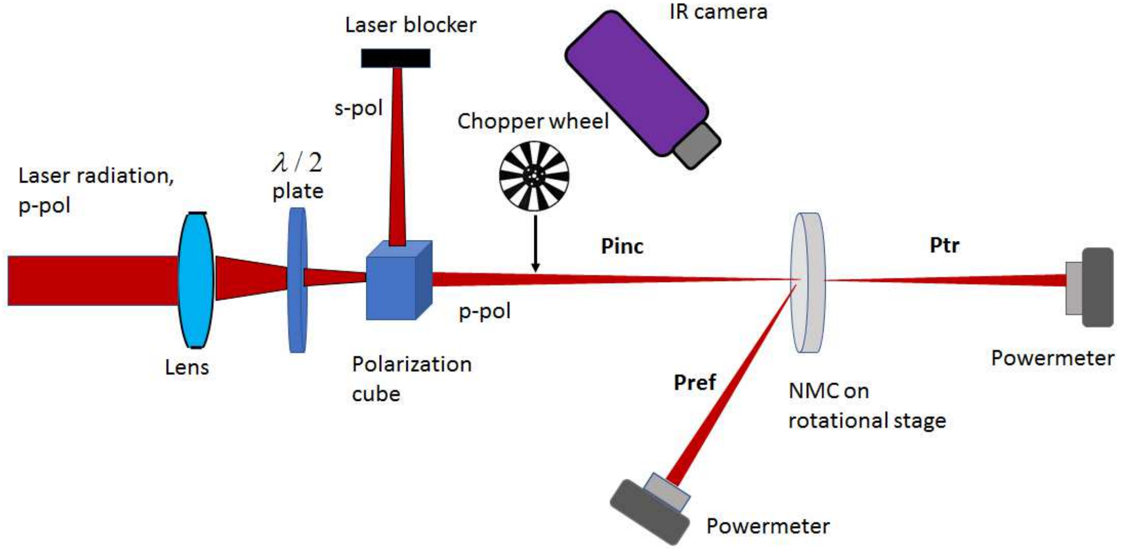
Edge filter in the angular mode

Reflectance at the central wavelength of 1030 nm vs. angle of incidence



The ratio $R_0:T_0$ can be set up by adjusting the angle of incidence

Experimental setup

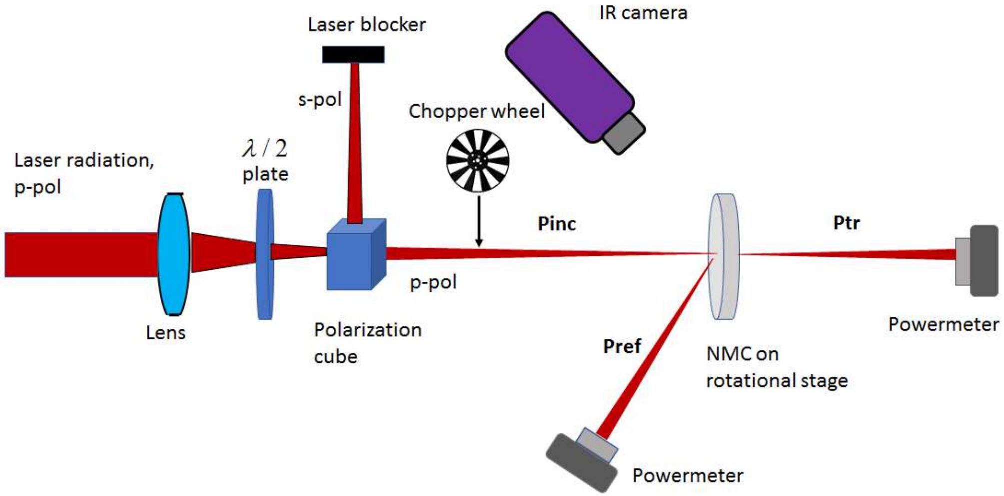


- Yb:YAG thin disk regenerative amplifier
- Repetition rate 50 kHz
- Pulse duration is 1 ps
- Beam radius 180 µm

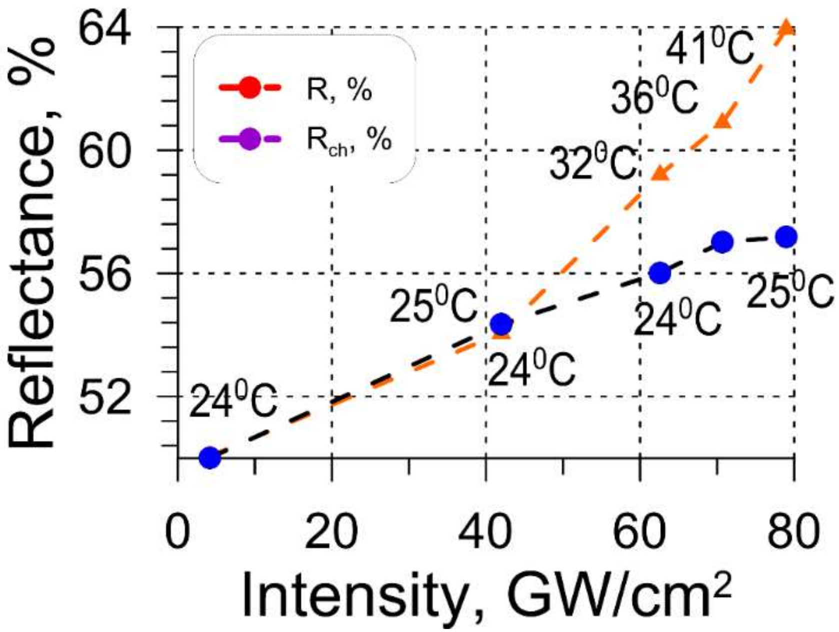
$$R = \frac{P_{ref}}{P}, \quad T = \frac{P_{tr}}{P}$$

Initial ration R_0:T_0 is specified by adjusting the incident angle at low incident power of 100 mW.

Intensity dependent measurements



- Optical chopper wheel, duty cycle 10%

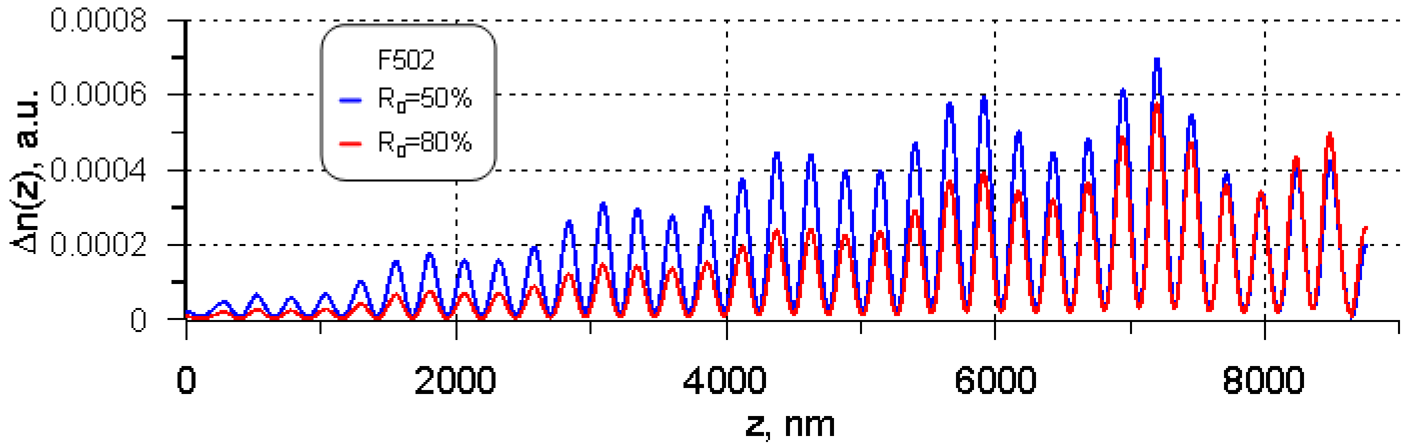


$$R(I) = \frac{P_{ref}}{P}, \quad T(I) = \frac{P_{tr}}{P}, \quad I = \frac{2P}{f_{rep} r^2 \tau}$$

Calculation of the nonlinear response of optical multilayers

- Calculations of R/T of the multilayers in the nonlinear regime are based on the solution of the system of Maxwell equations describing the propagation of light through a multilayer system.
- Dependence of the refractive index along the coating coordinate is taken into account:

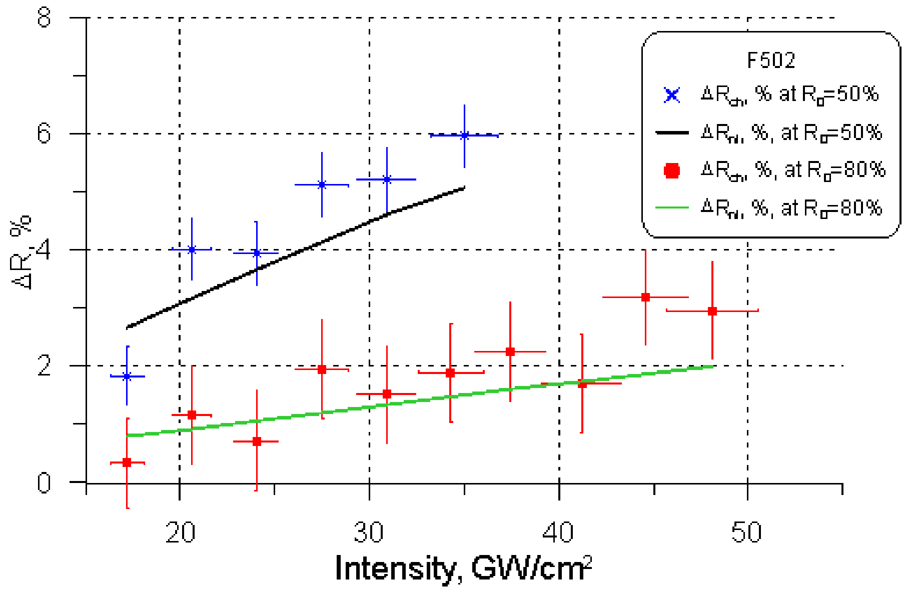
$$\Delta n(z) = n_2 I(z) = n_2 |E(z)|^2$$



Example: Dependence of nonlinear refractive index variation along the coating coordinate at different AOI

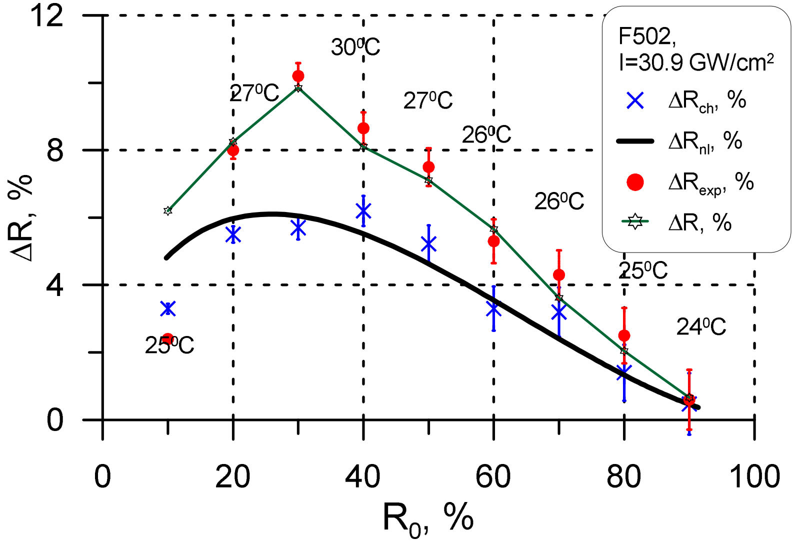
Comparison with experiment

n_2 + Parameters of the laser pulse + Design → Intensity dependent spectral characteristics *R(I)/T(I)*



Comparison of experimental modulation depth values without thermal effect and model calculations.

Determination of Kerr coefficient



Kerr coefficient of Nb_2O_5

$$n_2 = 2.2 \cdot 10^{-15} \frac{cm^2}{W}$$

$$\Delta R(I) \approx \Delta R_{nl}(I) + \Delta R_{\mathrm{Thermal}}(P, \Delta t)$$

$$\Delta R_{Thermal} = R\left(d_1 + \alpha_H \Delta t, d_2 + \alpha_L \Delta t, \ldots; n_H + \beta_H \Delta t, n_L + \beta_L \Delta t\right) - R_0$$

Results

- Novel dielectric edge filters exhibiting pronounced nonlinear increase of reflectance at high intensities have been demonstrated;
- The filters have been carefully characterized with the help of laser measurements as well as with photometric data;
- The nonlinear coefficient n_2 for Nb_2O_5 thin film material has been determined

Funding and Acknowledgements

- T. Amotchkina receives funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie agreement No 657596.

- DFG Cluster of Excellence, “Munich Centre for Advanced Photonics,” (http://www.munich-photonics.de).

- The authors are grateful to D. Ehberger, A. Ryabov, BoHan Chen, Y. Morimoto and P. Baum for providing and maintaining the laser source