MID-INFRARED IBS COATINGS FOR LASER APPLICATIONS

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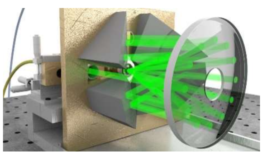
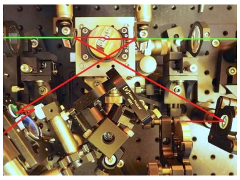
The Time and Frequency Lab at the University of Neuchatel

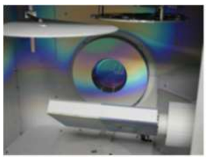
Novel ultrafast lasers and applications

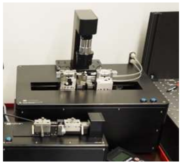




Advanced optical technologies

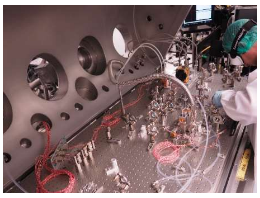
OPTICS platform: IBS coatings, evaluation, optimization.
Fiber technology.



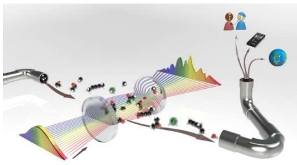


Optical frequency standards, atomic clocks

Spectroscopy and sensing



Frequency combs



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OPTICS: OPTical IBS Coatings for Swiss reseach

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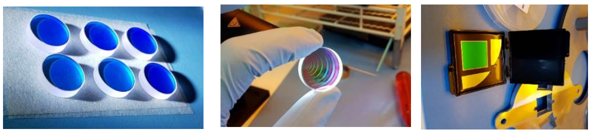
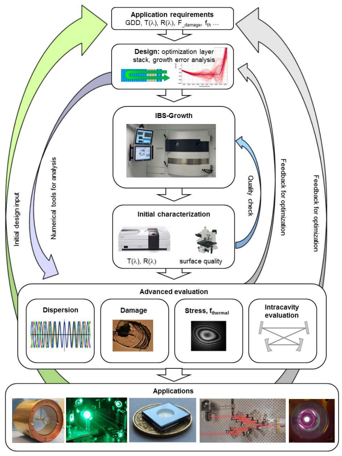
Provide full R&D chain for key enabling optics

Design → Fabrication → Character-ization → Experiment

- faster than industrial best efforts
  (1-3 weeks compared to 12-24 weeks)
- better performance due application adapted properties compared to off-the shelf optics
- optics with unique properties: competitive advantage of UniNE
- new solutions for IP and industrial collaborations





LTF is Partner of SNOP (Swiss National Optics Platform) with Swissphotonics, NTB, and EPFL

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Equipment of the OPTICS platform

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2013: IBS machine UniNE/SNSF
R'Equip: OPTICS: OPTical Ibs Coatings for Swiss research

2015: Fiber Processing UniNE/SNSF
R'Equip: Splicing and Glass Processing from Vytran, IBS fiber coatings

2017: IBS Optical Metrology in Deep-UV UniNE/SNSF
R'Equip: Ellipsometer, Monitoring Upgrade, Cavity Ring Down

2020: Spectrometer UniNE
Credit Inv.: CARY 5000 (with UMA)

Coming soon

2021: IBS Optical Metrology in Mid-IR
UniNE/SNSF
R'Equip: MIR-Ellipsometer, AFM, White light and Laser Interferometer

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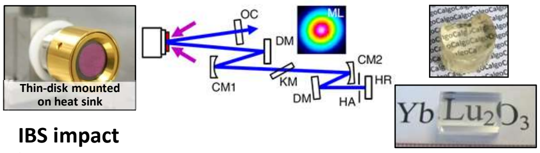
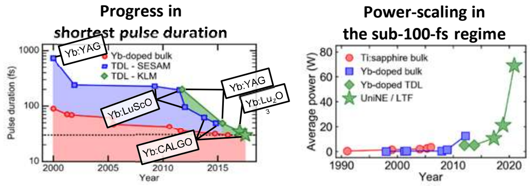
Highlights of the last years

Optics for ultrafast high power laser oscillators
Driving nonlinear processes that generate light from the Extreme ultraviolet up to Terahertz
Requirements:

- High LIDT (high pulse energies)
- low thermal response (high average power)
- High precision (dispersive mirrors and application tailored polarizing optics)

Progress of ultrafast thin-disk laser oscillators (key technology of LTF)





IBS impact

- ➢ Being among the first
  - ➢ Exploiting the benefits of novel materials
- ➢ Overcome technical limitations
  - ➢ Customized coatings for center wavelength
  - ➢ Broadband spectral properties
  - ➢ Fast development cycles

Scientific output enabled by IBS coatings

- ➢ Shortest pulses of any TDL oscillator
- ➢ Highest power of any sub-100-fs oscillator

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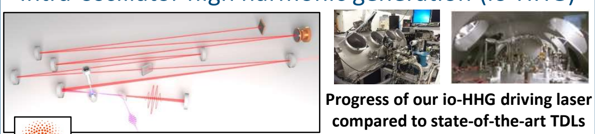
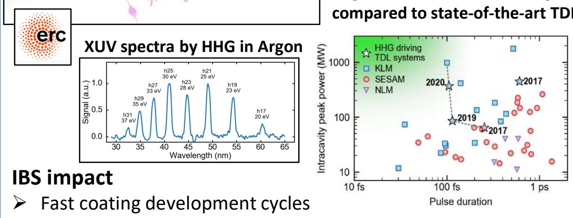
Intra-oscillator high harmonic generation (io-HHG) and io-THz

Intra-oscillator high harmonic generation (io-HHG)



Progress of our io-HHG driving laser compared to state-of-the-art TDLs



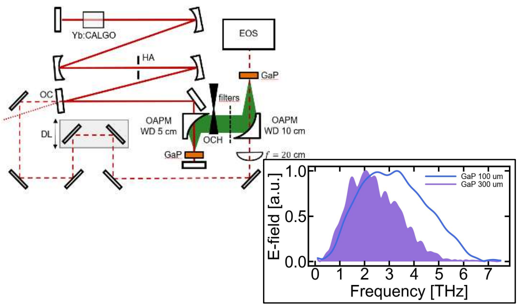
IBS impact

- ➢ Fast coating development cycles
  - ➢ Optimized for high damage threshold
  - ➢ On-demand components for power-scaling

Scientific output enabled by IBS coatings

- ➢ Giga-watt peak power inside sub-100-fs TDLs
- ➢ Progress in io-HHG within only 3 years
  - ➢ 3 orders of magnitude higher XUV flux
  - ➢ 2× higher photon energies

Intra-oscillator broadband THz-sources



IBS impact

- ➢ Customized anti-reflection coatings for semiconductor materials
- ➢ New class of intra-cavity enhanced nonlinear frequency conversion

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Novel concepts developed at LTF enabled by IBS coatings

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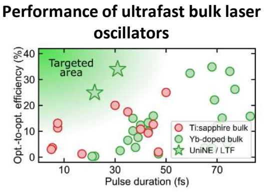
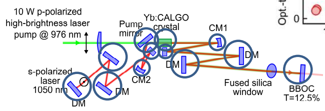
New pump concept for bulk oscillators

- for efficient sub-30-fs operation
- Requires tailored broad band optics





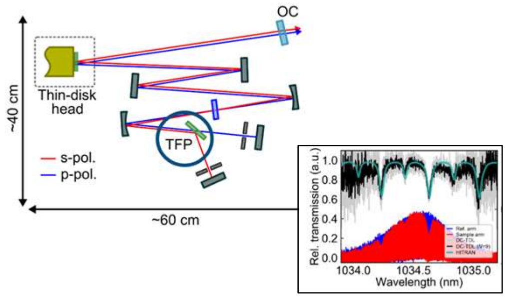
IBS impact

- ➢ All coated mirrors were manufactured by our IBS-coating facility
- ➢ In-house development: Idea, design, fabrication, characterization and experiment

Scientific output enabled by IBS coatings

- ➢ New class of sub-30-fs Yb-oscillators
- ➢ Record high performance in
  - ➢ Efficiency of any sub-30-fs oscillator
  - ➢ Power of any sub-30-fs Yb-oscillator

High-power dual-comb TDLs



IBS impact

- ➢ Optimized thin-film polarizer (TFP) enables dual laser operation via polarization splitting

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IBS Navigator 1100 CEC with Broadband Optical Monitoring

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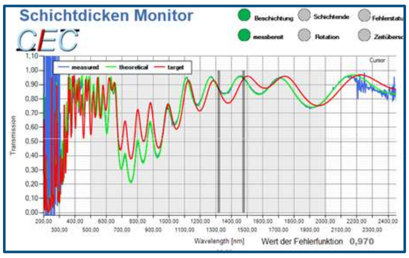
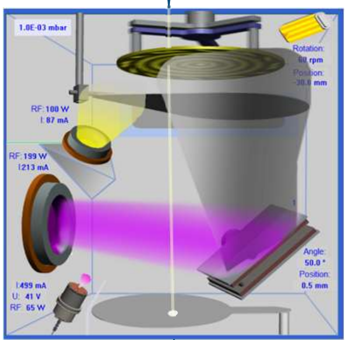
- Each second a transmission spectrum is acquired (probe, reference and background)
- Bandwidth ~230nm - 1100nm **(up to 2200nm since mid-2018)**



Spectrometer 1
230nm – 1020 nm

Spectrometer 2
1020nm – 2200 nm



- Precise monitoring of the layerthicknes

=> Exact optical properties of the materials are necessary

New material characterization for every change in the coating parameters for design und monitoring

To simulate the optical properties of the layer stack we use software (developed at UniNE) in python based on transfer matrix method.

Light source

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Extension of activities to the Mid-IR spectral region

- The OPTICS platform (OPTical IBS Coating for Swiss research) of UniNE provides growth of high quality optical thin film layers for numerous research areas
- Ion Beam Sputtering (IBS) allows
  - dense multilayer structures
  - with low losses
  - reduced defect densities
  - superior optical quality
- Strongly increasing interest for coatings in the mid-infrared (MIR) spectral region
- The MIR contains the fundamental ro-vibrational transitions of a wide range of molecules that are highly relevant in environmental, medical, industrial, and security applications
- However, progress in MIR optical systems is often hindered by lack of suitable optical coatings. Therefore, we started developing IBS MIR coatings
- The monitoring upgrade allowed us to develop processes for amorphous silicon by keeping the advantages of the optical monitoring

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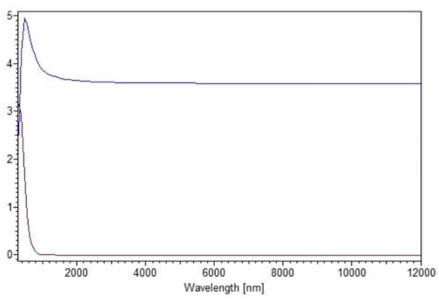
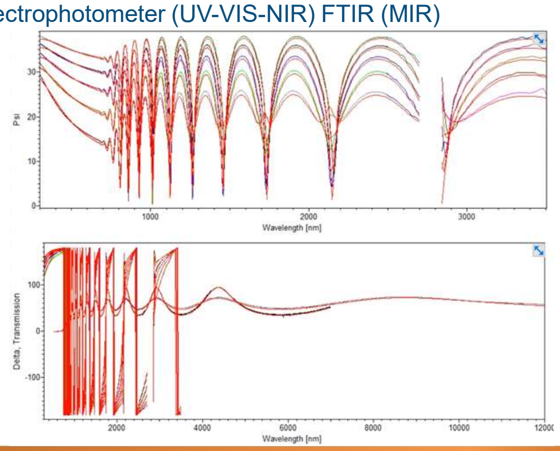
High index material a-Si

IBS0496 1216 nm a-Si was coated on
- Fused Silica (Corning 7980)
- CaF_2, ZnSe
- GaAs, InP

Material model
- Fitted to a 3 oscillator Tauc-Lorentz model



- Initially only transmission measurements and Selleier
- Ellipsometry with 5 angles (50°-70°) with Sellmeier model (190 nm – 3500 nm)
- Combined with transmission spectra of spectrophotometer (UV-VIS-NIR) FTIR (MIR)



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Dispersion control on QCL lasers

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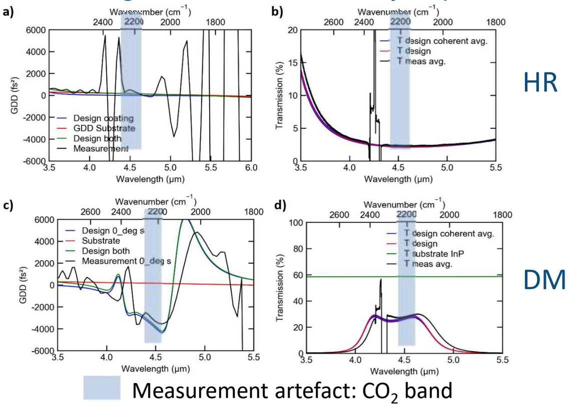
- Direct MIR frequency comb generation is highly attractive for the realization of spectral measurements that uniquely combine compactness, brightness, speed, and spectral coverage.
- Implementing a dispersion compensation QCL-facet coating allows to dramatically improve the comb operation regime [1]

Purpose: reduce the **group delay dispersion** (GDD) of 4-5 µm QCL comb devices

- designed and coated several layer stacks for flat and partial reflection combined with a flat dispersion of
- Characterization coatings on facets and on InP wafer
- Several materials were characterized for MIR coatings
  - Si, SiO_2, Ta_2O_5, Al_2O_3, HfO_2, …



[1] Gustavo Villares, Sabine Riedi, Johanna Wolf, Dmitry Kazakov, Martin J. Süess, Pierre Jouy, Mattias Beck, and Jérôme Faist, "Dispersion engineering of quantum cascade laser frequency combs," Optica **3**, 252-258 (2016)

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Beam splitters for 7.8 µm QCL dual comb setup

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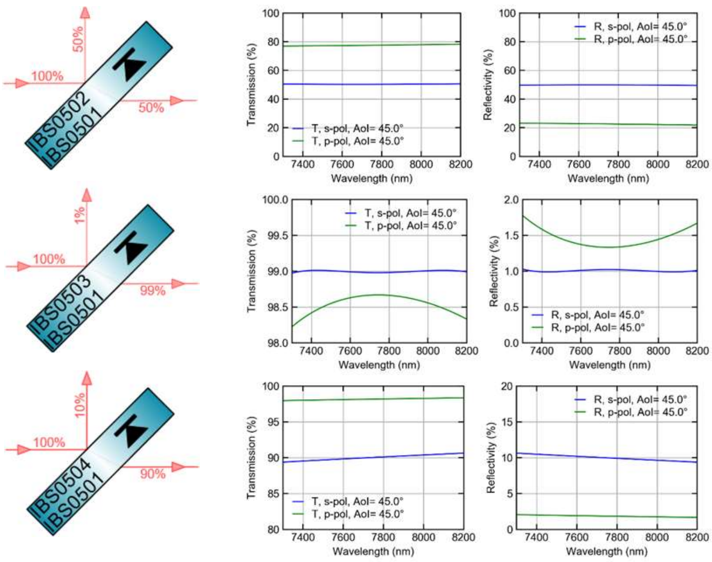
BS 50:50 for s-polarization

BS 1:99 for s-polarization

BS 10:90 for s-polarization



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Optics for ultrafast Cr:ZnS laser (2.4 µm)

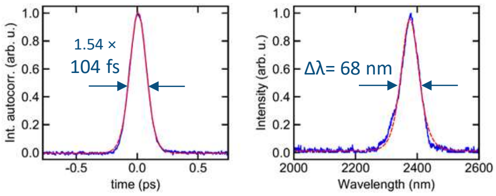
Ultrafast Cr:ZnS laser are attractive (tunable) sources emitting pulses in the spectral range between 2 µm and 3 µm which is attractive for:

- Direct application (spectroscopy, sensing, LIDAR)
- Driving nonlinear processes (further into IR)

In our KLM oscillators we realized in various configurations:

- Sub-100 fs
- Watt-level output power

Typical autocorrelation trace and output spectrum



We fabricated:

- pump mirrors (HT for the pump at 1550 nm) and HR for the lasing range (2200 – 2600 nm)
- High reflectors 2200 nm – 2600 nm and also with a-Si as high-n material 2000 – 2800 nm
- Output couplers for (3%, 5% and 10%) also provided OC for [1]
- No dispersive mirrors were required here due to the negative dispersion in conventional materials as YAG and CaF_2, ZnSe, Sapphire (DMs only needed for TOD compensation[2])

[1] A. Barh, J. Heidrich, B. O. Alaydin, M. Gaulke, M. Golling, C. R. Phillips, and U. Keller, "Watt-level and sub-100-fs self-starting mode-locked 2.4-µm Cr:ZnS oscillator enabled by GaSb-SESAMs," Opt. Express **29**, 5934-5946 (2021)

[2] N. Nagl, S. Gröbmeyer, V. Pervak, F. Krausz, O. Pronin, and K. F. Mak, "Directly diode-pumped, Kerr-lens mode-locked, few-cycle Cr:ZnSe oscillator," Opt. Express **27**, 24445-24454 (2019)

Conclusion and outlook

IBS with BBM: resistant coatings with precise thickness control:

- Exact material characterization is required: Ellipsometry combined with transmission data (Spectrophotometer and FTIR)

Ultrafast pulses with high power (NIR)

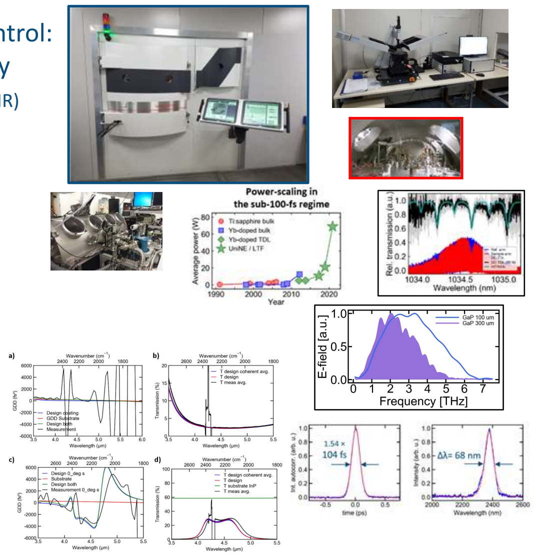
- HHG and THz can be generated
- Broadband dispersive mirrors for shorter pulses

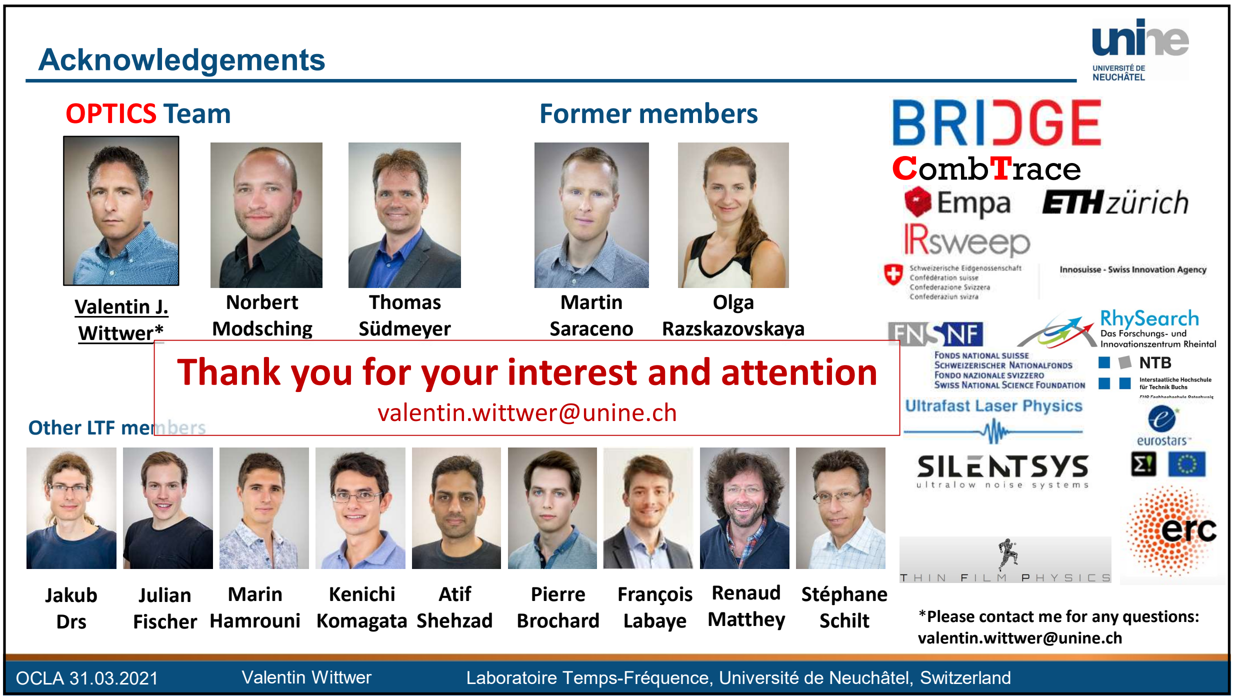
MIR

- Optics set for Cr:ZnS laser
- Dispersive coatings in the MIR for QCLs
- Beamsplitters for spectroscopic setup at 7.8 µm

Outlook

- Advanced material characterization with new equipment
- Extended material range with upgrade for the deposition of nitrides and oxynitrides

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THIN FILM PHYSICS
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