Terahertz time domain spectrometer to characterize nonlinear materials for efficient terahertz generation

Frederike Ahr[1,2], **Sergio Carbajo**[1,2], **Giovanni Cirmi**[1], **Oliver D. Mücke**[1], **Xiaojun Wu**[1] , **and Franz X. Kärtner**[1,2,3]

[1] Center for Free Electron Laser Science, Deutsches Elektronen Synchrotron, Notkestraße 85, 22607 Hamburg, Germany

[2]Department of Physics, University of Hamburg, 22761 Hamburg, Germany

[3]Department of Electrical and Computer Engineering, and Research Laboratory of Electronics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA

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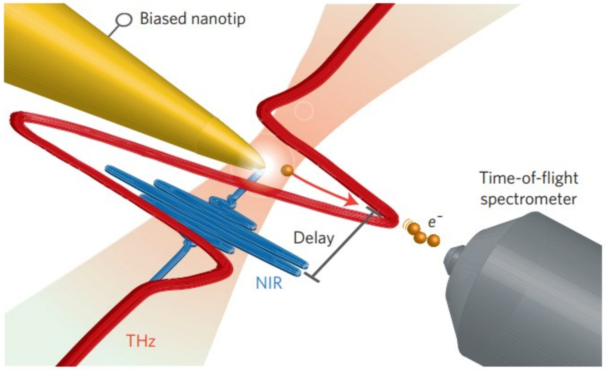
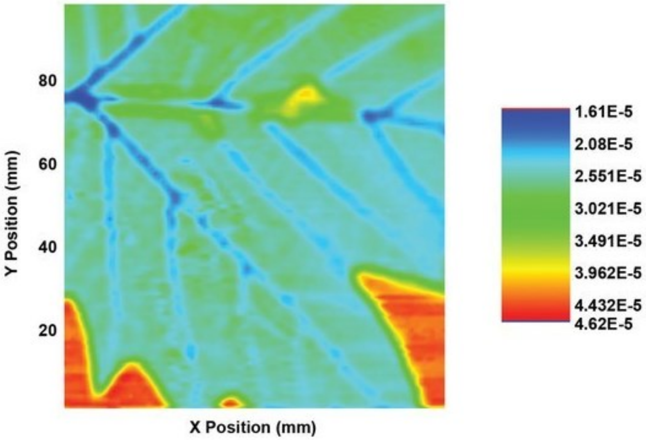
3. März 2015

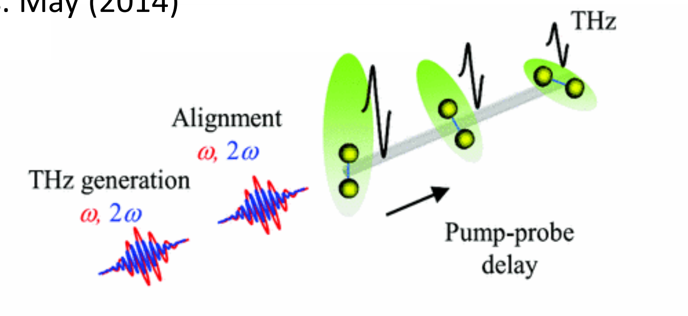
Motivation for Efficient High-Power THz Generation



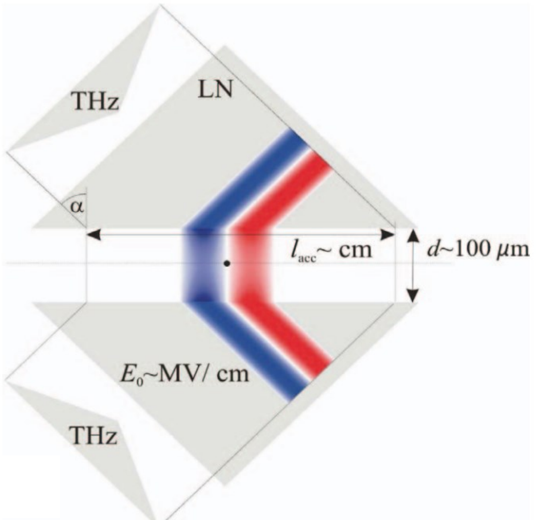
L. Wimmer et al., Nat. Phys. May (2014)

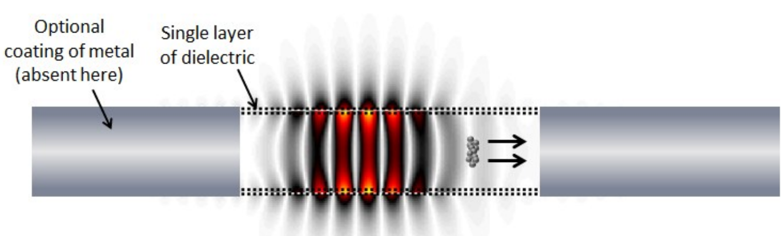


P. U. Jepsen et al., Laser & Photonics Rev **5** (2011)
Source: Menlo Systems



S. Fleischer et al., PRL **107** (2011)





L. J. Wong et al., Opt. Exp. **21** (2013)

L. Pálfalvi et al., Phys. Rev. STAB **17** (2014)

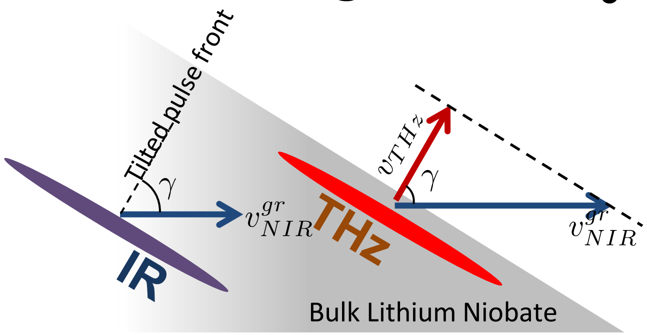
Highly Efficient THz Generation

- **Mechanisms for generating highly efficient single-cycle THz radiation by using optical rectification**
  - non collinear optical rectification
    - lithium niobate (LN), lithium tantalate (LT), GaAs
  - collinear optical rectification
    - ZnTe, GaP, organic crystals

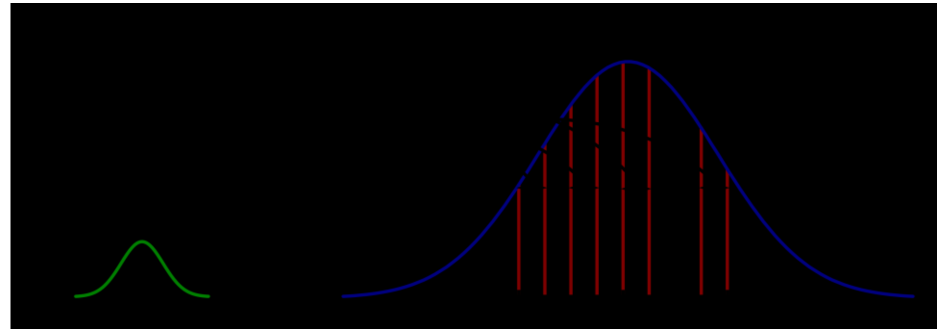
- **Goal:**
  - highly efficient THz single-cycle pulse in the regime of 0.1 - 1 THz
  - characterization of the nonlinear optical materials in sub THz regime
    - Lithium niobate known as promising material
      - high susceptibility
      - non collinear phase matching $n_{THz} > n_{NIR}^{gr}$

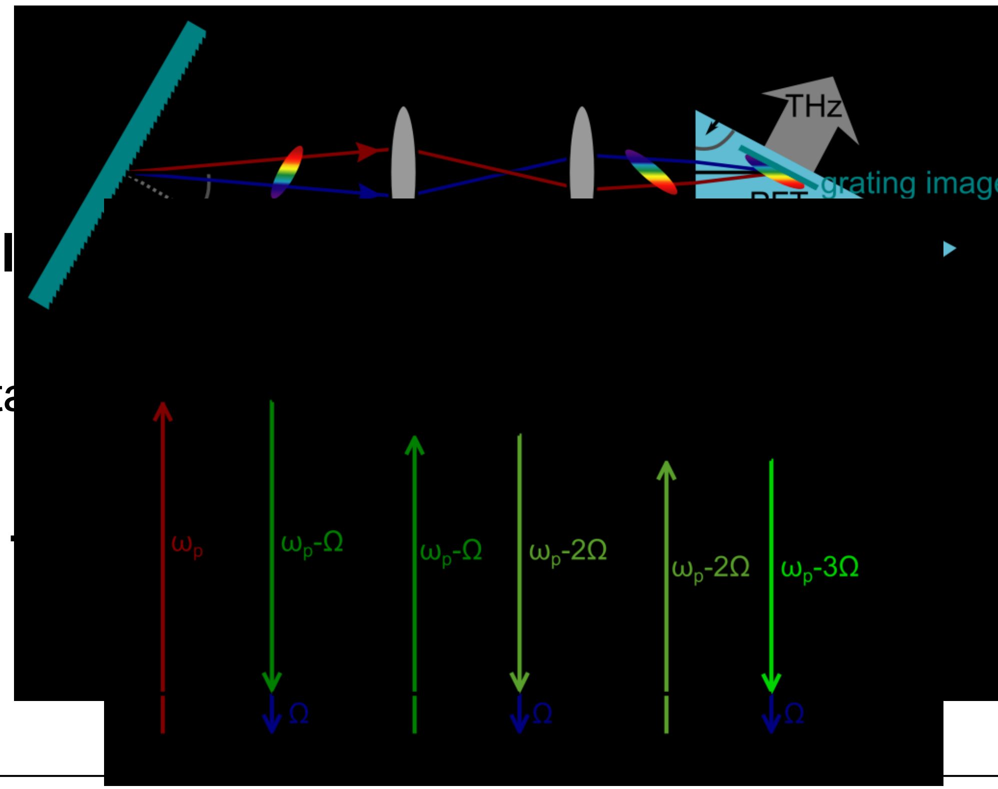
Pulse Front Tilting of the Intensity Front

- **Phase matching in $LiNbO_3$ for OR**



$$v_{\mathrm{NIR}}^{\mathrm{gr}} \cos\gamma = v_{\mathrm{THz}}$$





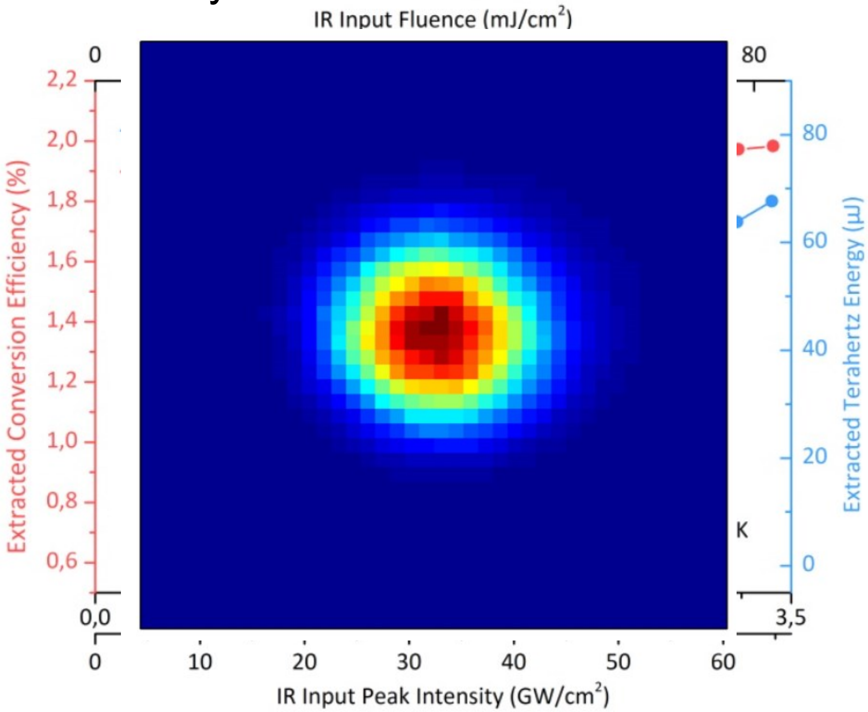
- **Grating induces a pulse-front til**
  - Image of grating in the crystal
  - Higher peak intensity on the crysta

- **Enhancement of efficiency due t cascading of pump pulse**

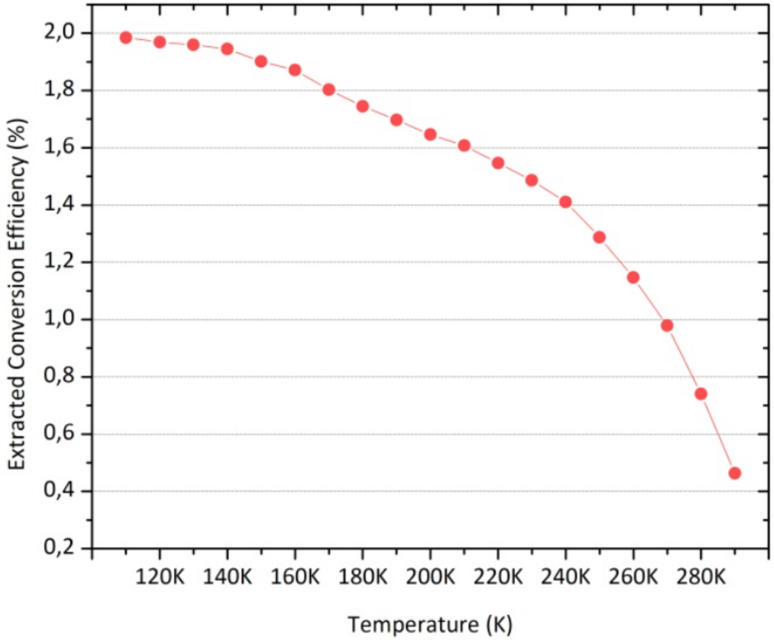
J. Hebling et. al (2002), S.W. Huang et al. (2013)

Efficient THz Generation at 1.03μm

- **Extracted THz beam**
  - Conversion efficiency
    - 0.72% at room temperature
    - 2% at cryogenic temperature
  - 68μJ THz energy
  - 0.2 GV/m THz field strength
  - Nearly diffraction-limited Gaussian beams

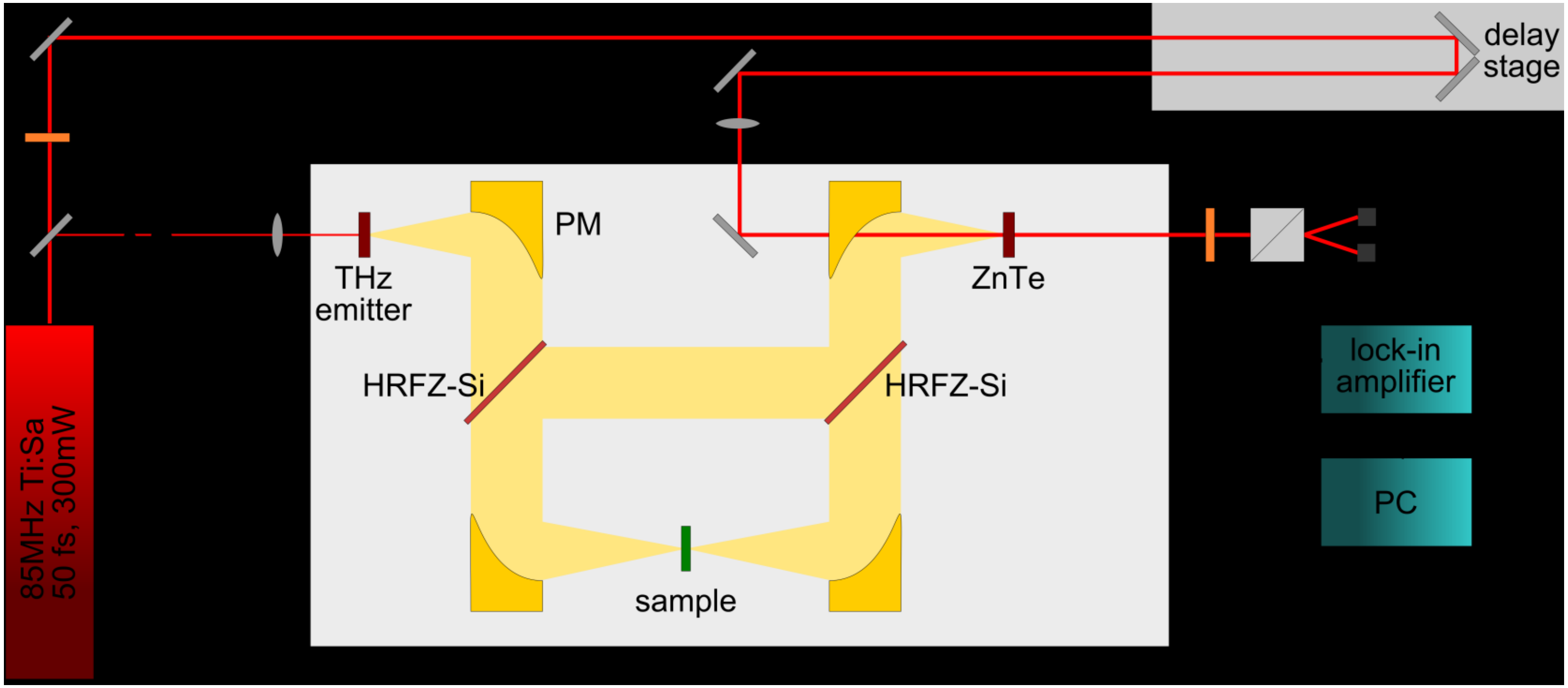


- **Efficiency enhancement at cryogenic temperature due to**
  - lower THz absorption
  - longer propagation length



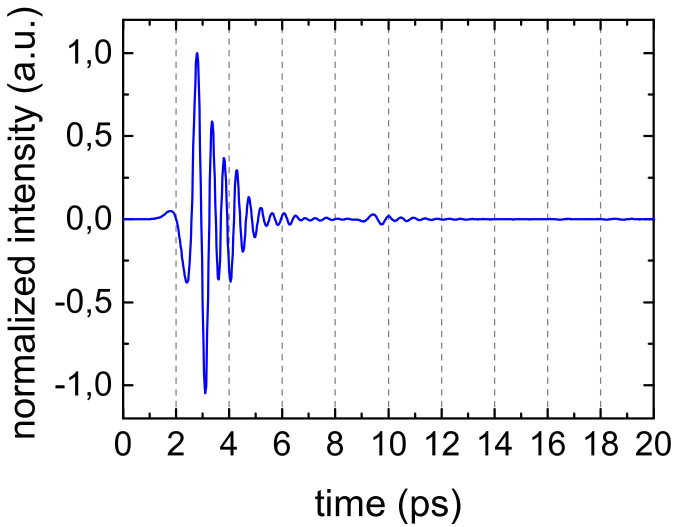
THz Time Domain Spectrometer

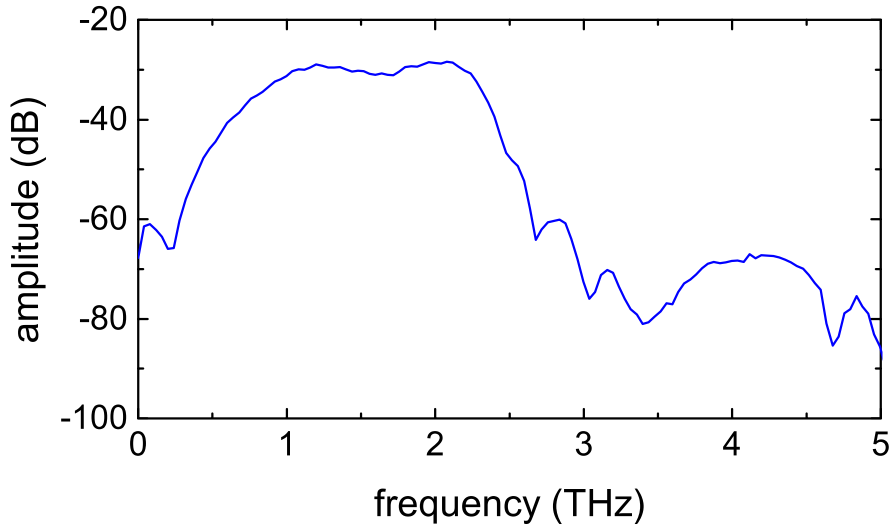
- **Real pulse response via electro-optical sampling**
  - THz emitter
    - ZnTe crystal
    - LT-GaAs antenna
  - Transmission, reflection and absorption spectra



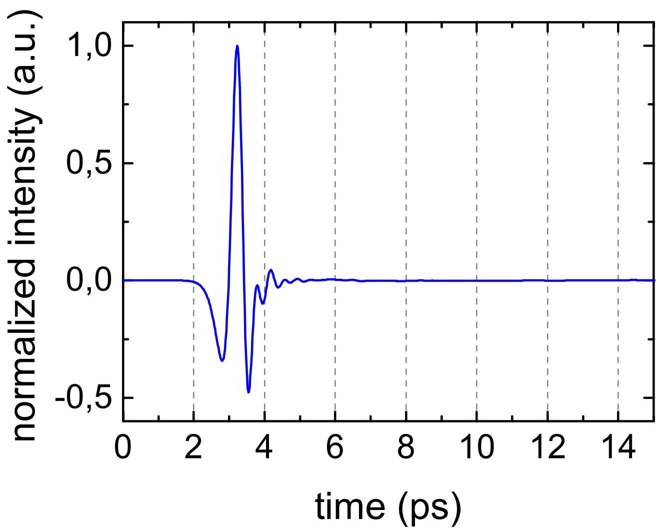
THz Emitters – Temporal Waveforms

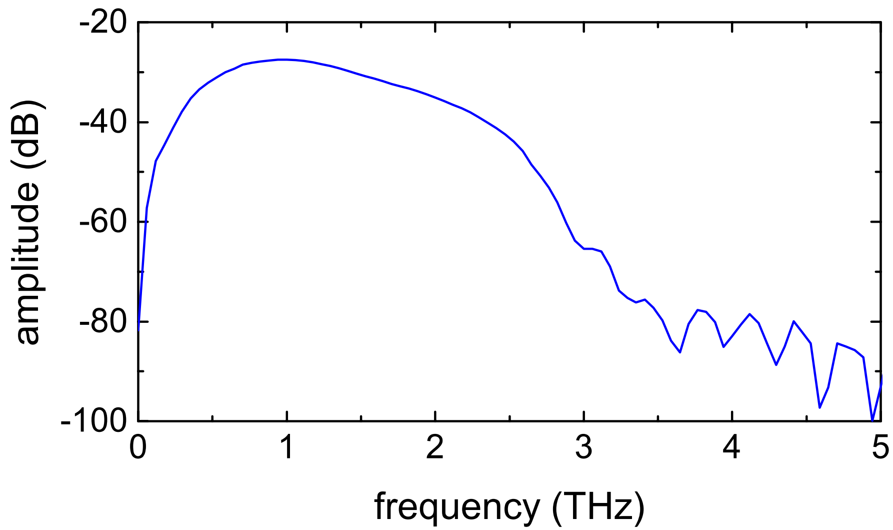
- **ZnTe**





- **LT-GaAs antenna**

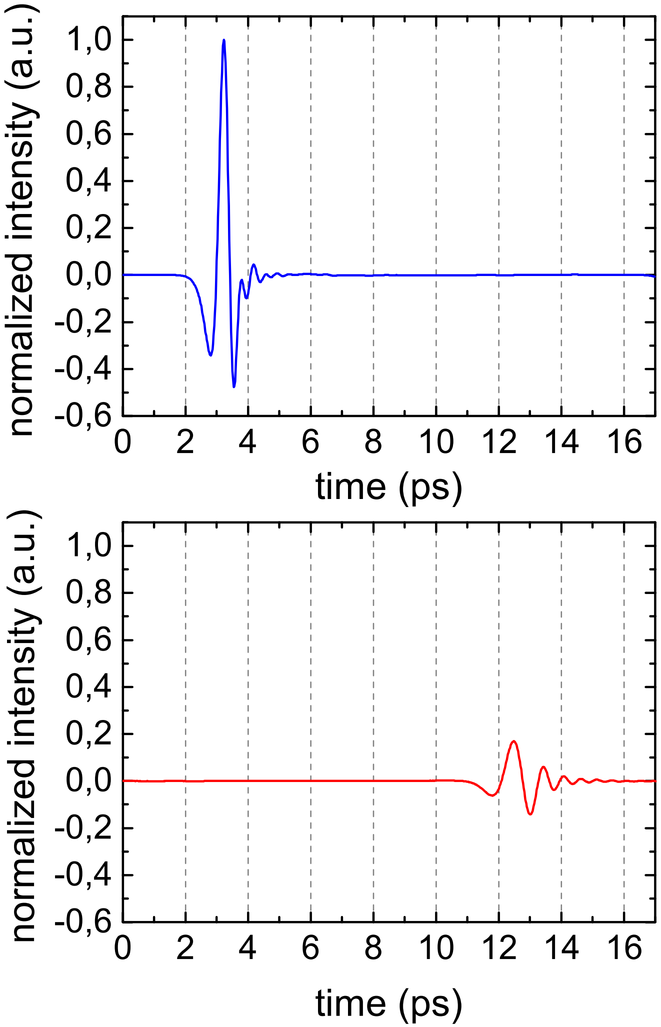


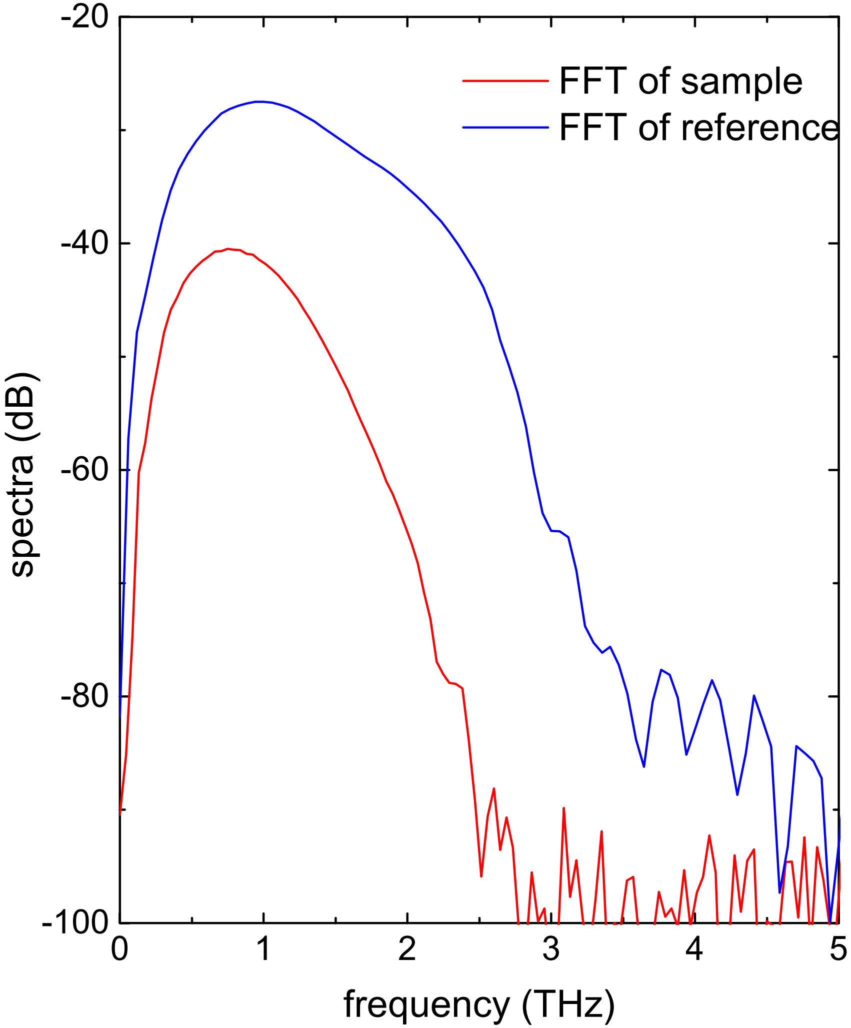


Data in collaboration Peking University

THz Transmission Spectrum of Antenna

- **Temporal profile and spectrum of doped lithium niobate**





THz Transmission Spectrum to Characterize Sample

- **Temporal profile and spectra of reference and sample allows conclusion for**
  - refractive index

$$n_2(\omega) = \frac{\Phi(\omega)c}{\omega d} + 1$$

  - extinction coefficient

$$\kappa_2(\omega) = \frac{-ln(\rho(\omega)\frac{[n_2(\omega)+1]^2}{4n_2(\omega)})c}{\omega d}$$

  - absorption coefficient

$$\alpha = \frac{2\omega\kappa}{c}$$

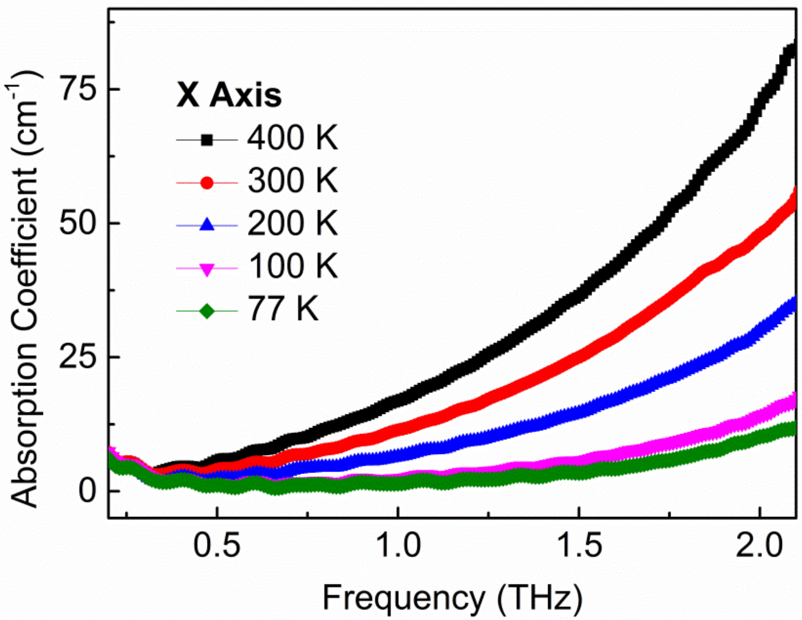
phase

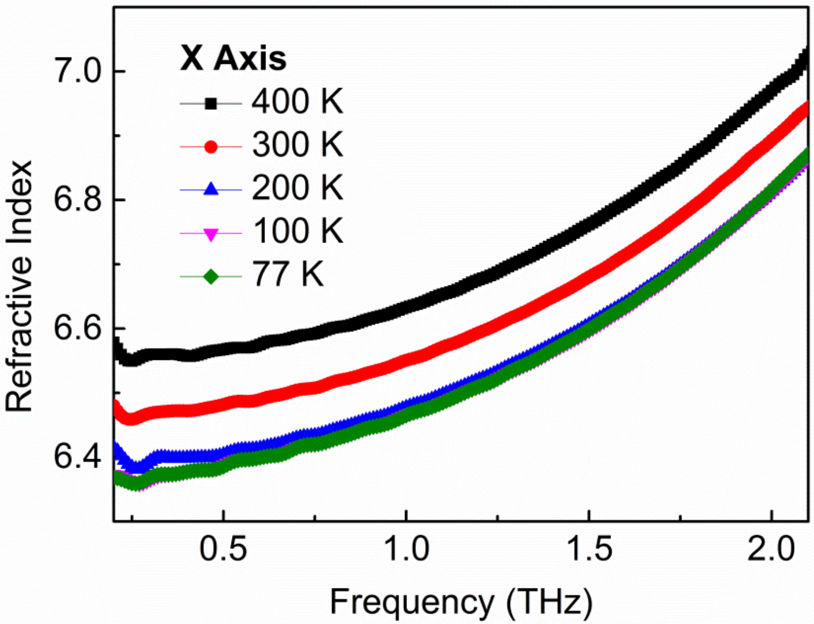
amplitude

sample thickness

Preliminary Characterization of Lithium Niobate

- **THz-TDS at Peking University**
  - amplified Ti:Sa with GaAs antenna

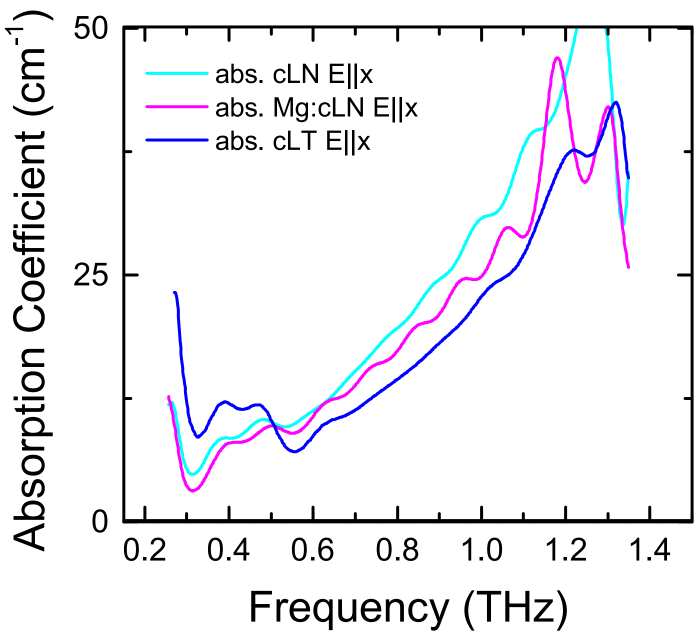


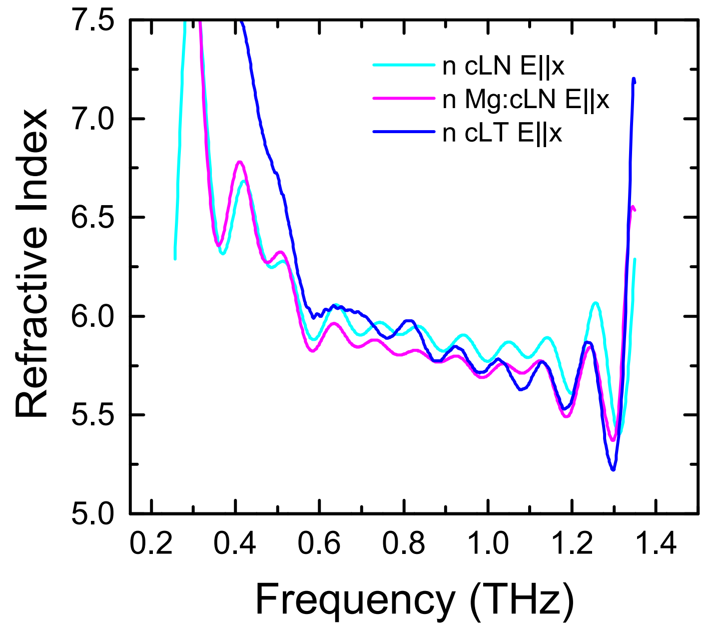


Preliminary characterization: FTIR

- **Applying independent methods to verify refractive index and absorption coefficient**

- **Measurement of LN and LT**
  - FTIR with Bolometer

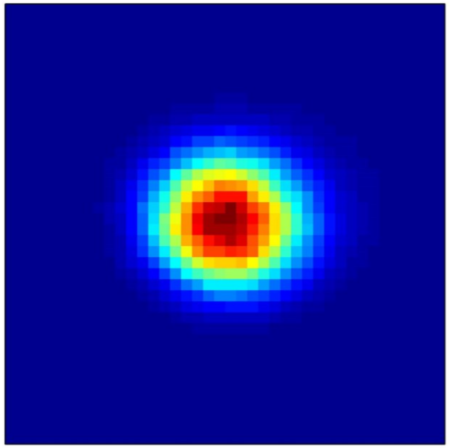




Data in collaboration A. Cavalleri

Final Remarks

- **Efficient THz generation important for numerous applications**



- **Intensity pulse front tilting in lithium niobate**
  - 2% extracted conversion efficiency
- **Setup to characterize nonlinear optical materials at different temperatures in the sub THz regime**
  - THz time domain spectrometer
  - Refractive index and absorption coefficient
- **Understanding the material promise further improvement of efficient THz generation**

Thank you for your attention

European Research Council
Established by the European Commission

Ti:Sapphire oscillator

- **Pump laser for THz-TDS**

$$f_{\mathrm{rep}} = 85\,\mathrm{MHz} \qquad P_{\mathrm{out}} = 350\,\mathrm{mW}$$

$$\lambda_c = 805\,\mathrm{nm} \qquad \tau = 50\,\mathrm{fs}$$