Simulation of High Energy Terahertz Generation with Consecutive Stages

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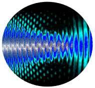
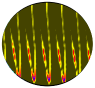
DESY, Center for Free-Electron Laser Science (CFEL),
Ultrafast optics and X-ray Division

Overview



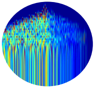
1. Motivation

- Why Terahertz.



2. Multi-cycle Terahertz Generation

- Cascading Process
- Phase Matching



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- Consecutive Stages Setup
- Dispersion Compensation

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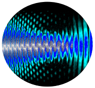

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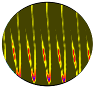

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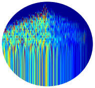

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Motivation

- **What is Terahertz wave (1 THz=10^{12} Hz)**:
  [100 μm, 1 mm] $\Rightarrow$ [0.3 THz, 3 THz]

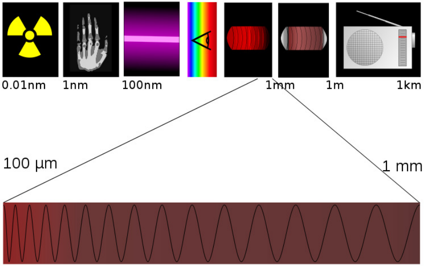

Figure: Terahertz wavelength[1]

[1]Wikipedia contributors, *Terahertz radiation — Wikipedia, The Free Encyclopedia.*

Motivation

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- **What are the applications:**

Motivation

- **What is Terahertz wave (1 THz=10^{12} Hz)**:
  [100 μm, 1 mm] $\Rightarrow$ [0.3 THz, 3 THz]
- **What are the applications:**
  spectroscopy[2], spin dynamics control[3] , linear electron acceleration[4], security detection[5]

[2] Markelz, Roitberg, and Heilweil, "Pulsed terahertz spectroscopy of DNA, bovine serum albumin and collagen between 0.1 and 2.0 THz".

[3] Kampfrath et al., "Coherent terahertz control of antiferromagnetic spin waves".

[4] Nanni et al., "Terahertz-driven linear electron acceleration".

[5] Kemp, "Millimetre wave and terahertz technology for detection of concealed threats-a review".

Motivation

linear electron acceleration[6] ⇒ table-top X-ray source

- Acceleration field: 1.3 GHz
- Size: ∼ 100 m
- Electron beam energy: 1.25 GeV
- Accelerating gradient: 12.5 MeV/m

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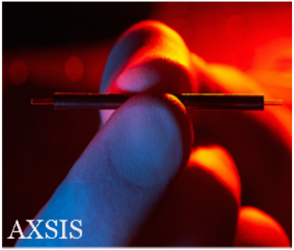
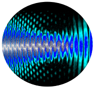


- Acceleration field: 0.3 THz
- Size: ∼ 10 cm
- Electron beam energy: 20 MeV
- Accelerating gradient: 200 MeV/m

[6] Nanni et al., "Terahertz-driven linear electron acceleration".

Overview



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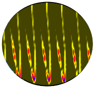

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   - Cascading Process
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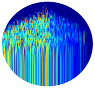

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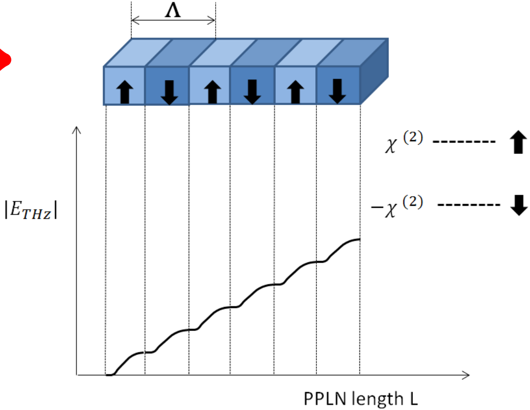
Multi-cycle Terahertz Generation

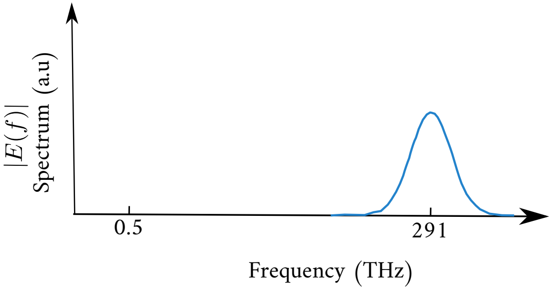
Periodically Poled Lithium Niobate(PPLN).

I'm the pump



Cascading Process

$\chi^{(2)}$ process



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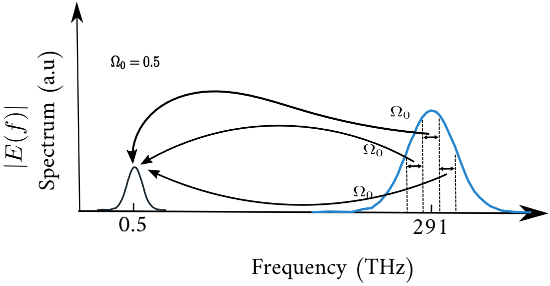
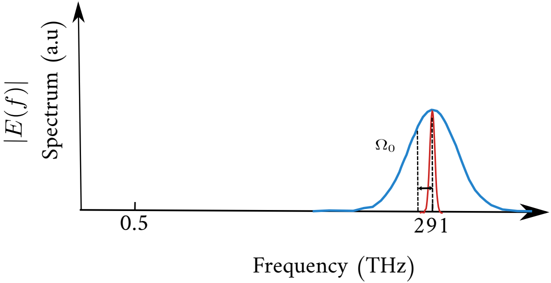


Cascading Process

$\chi^{(2)}$ process
damage of crystal $\propto \sqrt{\tau}$



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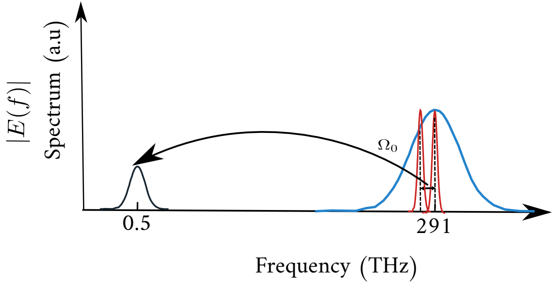

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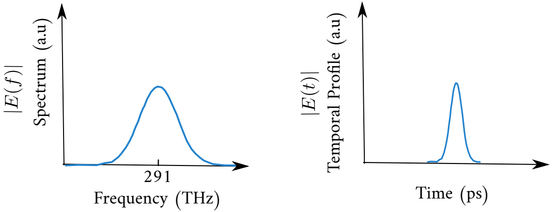

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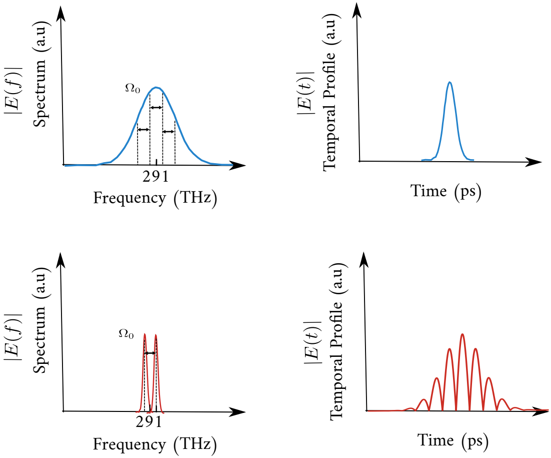
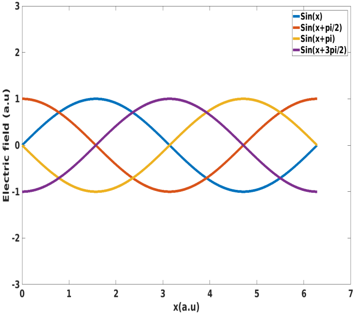
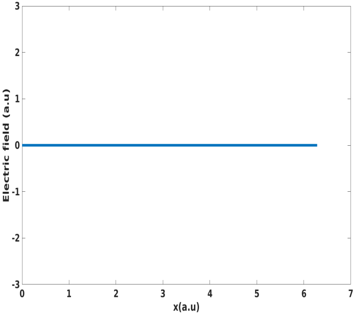


Phase Matching

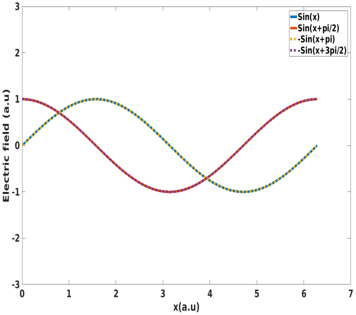


(a) 4 field with different phase

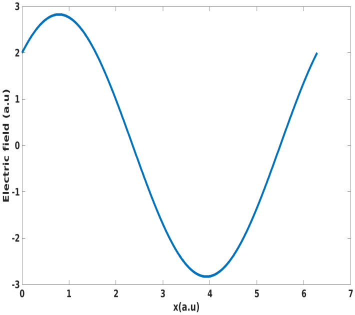


(b) Result of summation of 4 fields

Phase Matching



(c) 4 field with flipped phase



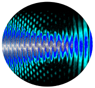
(d) Result of summation of 4 fields

Short VS Long Pump Pulse

- Modify terahertz temporal profile .
- Enhance terahertz efficiency.

'U' Shape Instantaneous Spectrum:

Overview



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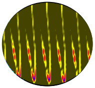

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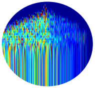

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High Energy Terahertz Generation with Consecutive Stages

Main Challenges of High Energy Terahertz:

High Energy Terahertz Generation with Consecutive Stages

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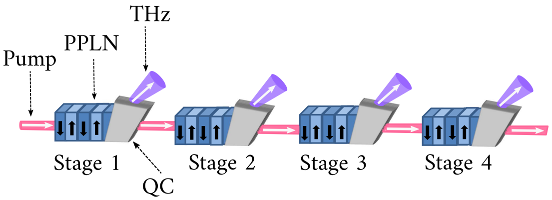
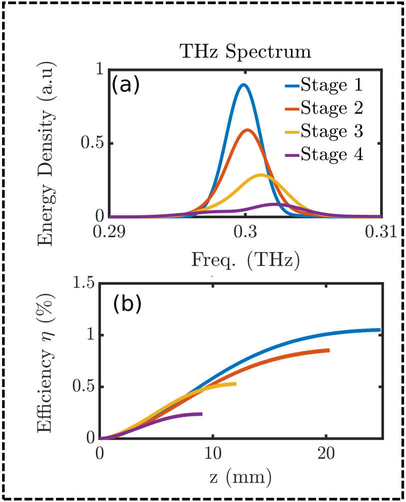


Figure: Quartz Coupler (QC), Periodically Poled Lithium Niobate (PPLN)

Consecutive Stages

Direct Pump Pulse Recycling



Consecutive Stages

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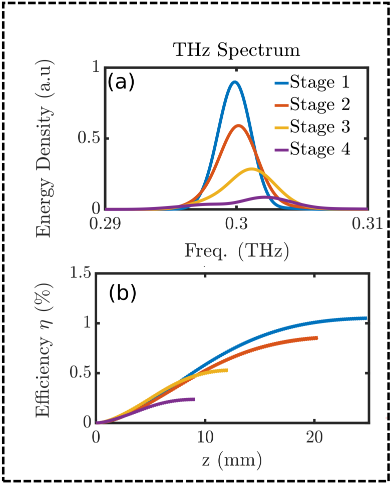
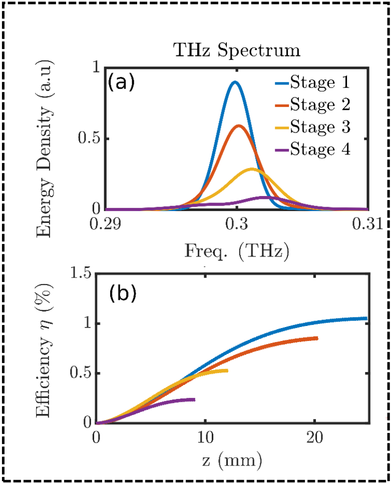


- efficiency reduces after each stage.

Consecutive Stages

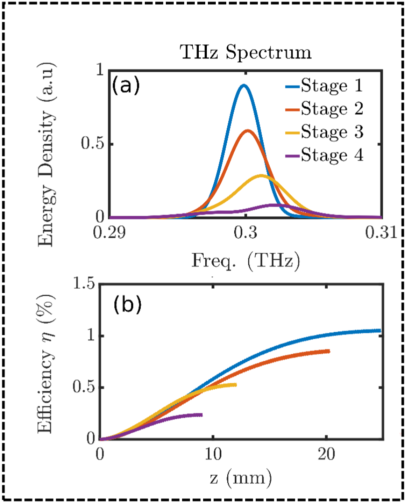
Direct Pump Pulse Recycling



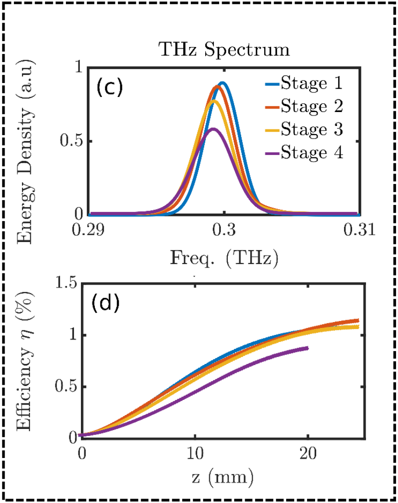
- efficiency reduces after each stage.
- terahertz spectrum becomes broader.

Consecutive Stages

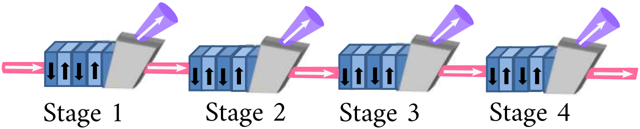
Direct Pump Pulse Recycling



with Pump Pulse
Dispersion Compensation



Multi-stage Setup



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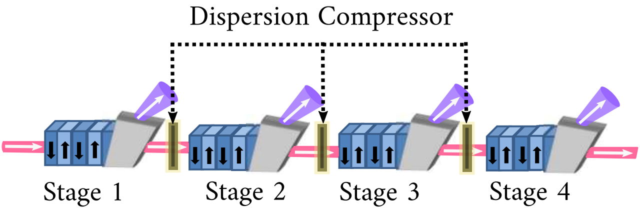
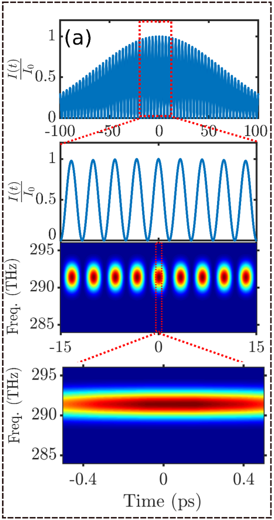


Short Time Fourier Transform (Instantaneous Spectrum)

Input Pump



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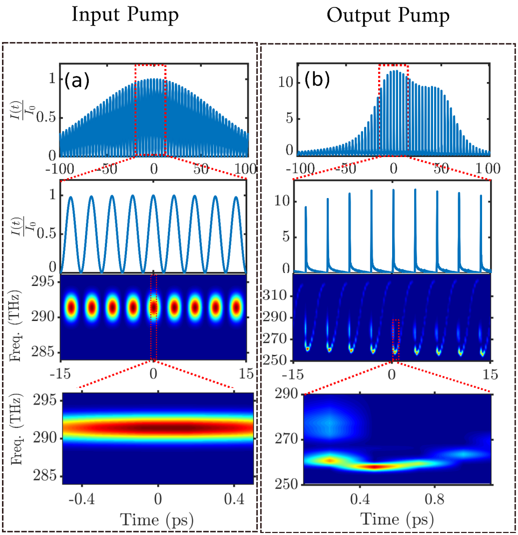

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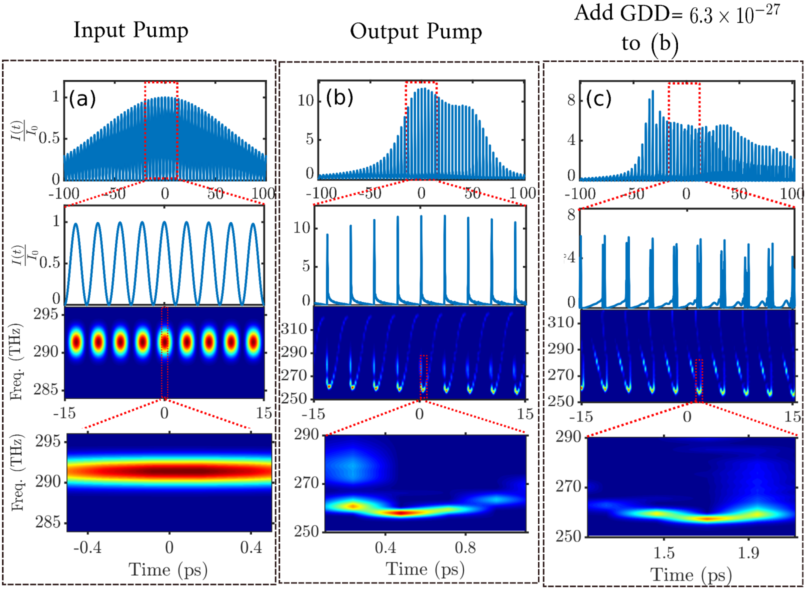
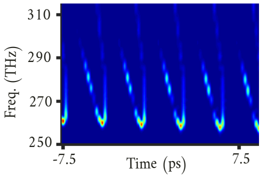
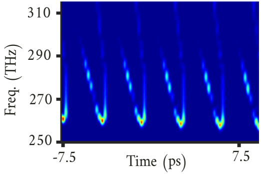


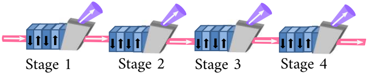
Conclusion



- Cascading process induces U shape instantaneous spectrum on the pump pulse.

Conclusion





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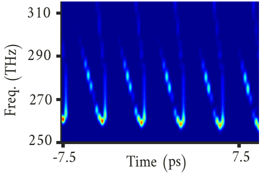

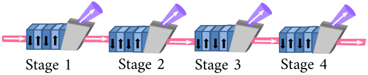

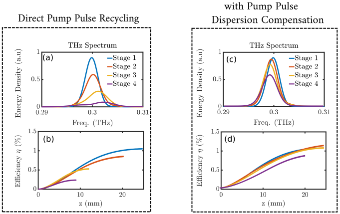

- Cascading process induces U shape instantaneous spectrum on the pump pulse.
- Pump pulse recycling enhances terahertz generation efficiency.
- Dispersion compensation further enhances terahertz generation efficiency.

The end of *this presentation!
Thank you for your attention!

Many many thanks to the AXSIS team

Reference I

[1] Tobias Kampfrath et al. "Coherent terahertz control of antiferromagnetic spin waves". In: *Nat. Photonics* 5.1 (2011), pp. 31–34.

[2] Michael C Kemp. "Millimetre wave and terahertz technology for detection of concealed threats-a review". In: *Infrared and Millimeter Waves, 2007 and the 2007 15th International Conference on Terahertz Electronics. IRMMW-THz. Joint 32nd International Conference on*. IEEE. 2007, pp. 647–648.

[3] AG Markelz, A Roitberg, and Edwin J Heilweil. "Pulsed terahertz spectroscopy of DNA, bovine serum albumin and collagen between 0.1 and 2.0 THz". In: *Chem. Phys. Lett* 320.1 (2000), pp. 42–48.

[4] Emilio A Nanni et al. "Terahertz-driven linear electron acceleration". In: *Nat. Commun* 6 (2015), p. 8486.

Reference II

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