Design of a reflective PEPC for 100J/10Hz amplifier

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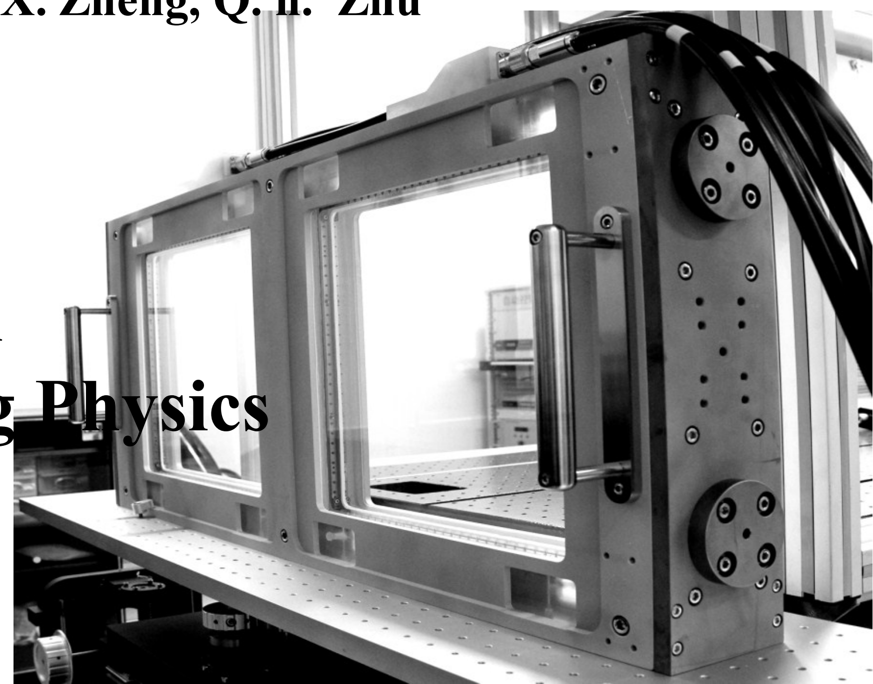

Outline

- Introduction
- Story of steps towards HEC-RF requirements
- Design and performances of a R-PEPC
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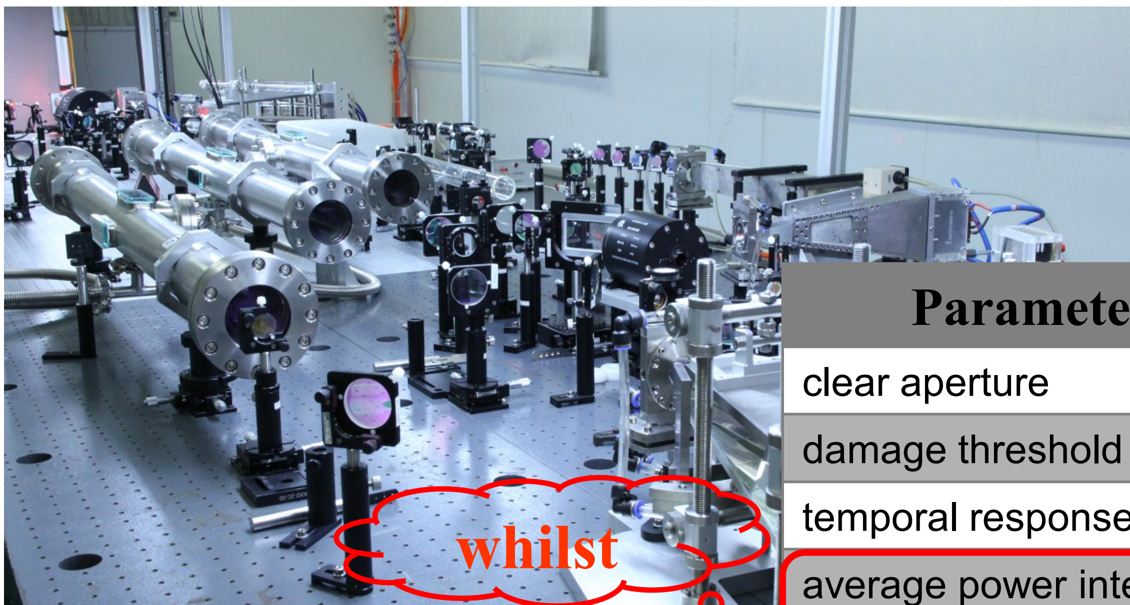
Introduction

- Merits of multi-pass amplifying scheme have been validated in respect of high extraction efficiency, cost saving, and physical size reducing
- In this amplifier, an optical switch is required for laser pulse injecting, ejecting, and parasitic oscillation suppressing
- As for high energy, repetition rate operating, large laser facility



whilst

Parameter	Performance
clear aperture	multi-cm to tens of cm
damage threshold	mulit-J/cm^2
temporal response	nanoseconds-scale
average power intensity	tens W/cm^2
repetition rate	around 10 Hz

Introduction

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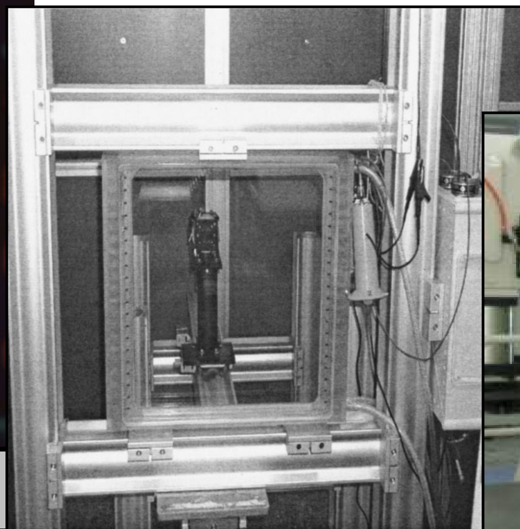
Meeting the required aperture size, damage threshold, temporal response

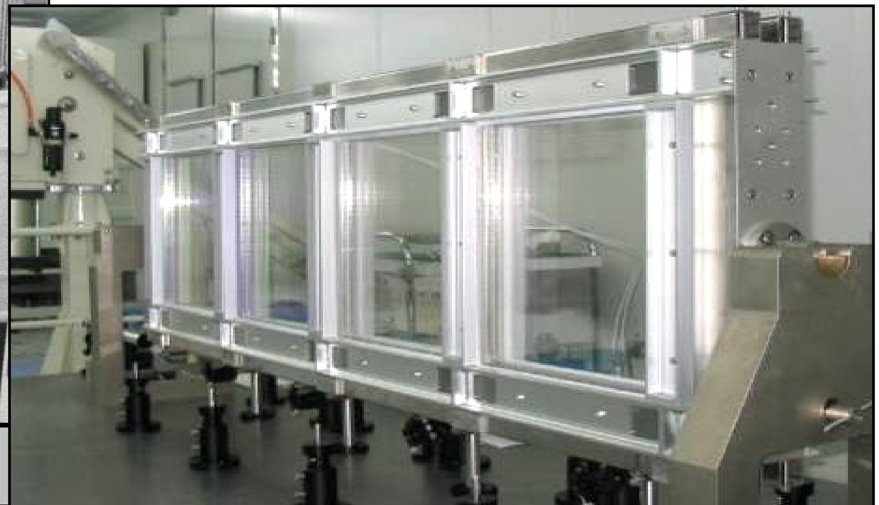
Using thin EO crystal while keeping switching voltage at a low level

Make it appropriate for HEC-rf operation

For NIF in LLNL



For LMJ in CEA



For SG-Ⅲ in RCLF

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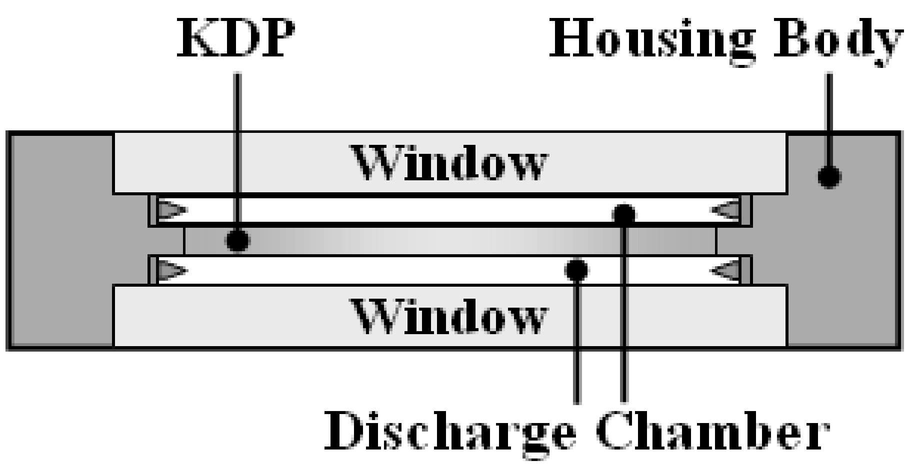
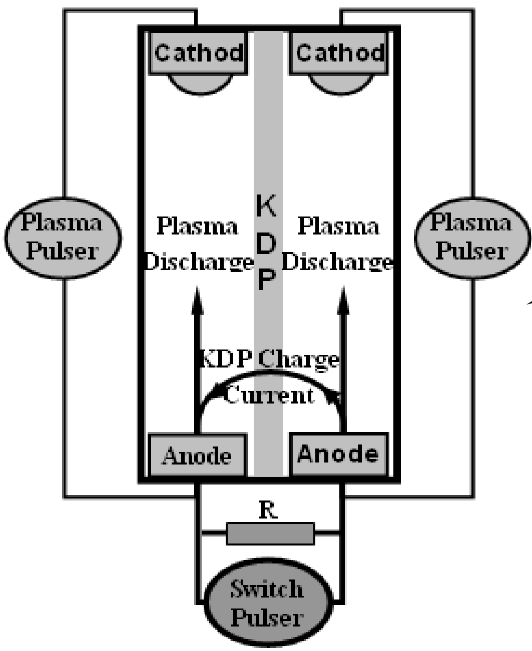
Briefly Introducing the concept of PEPC



Schematic of the PEPC architecture

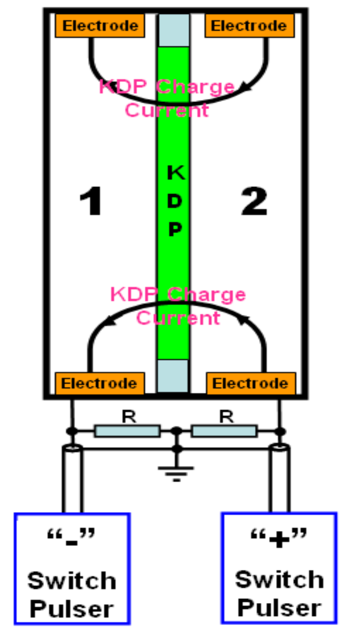
Two kinds operating mode



S1: High-current ionizing

S2: Switching voltage

Only the switching voltage



Double pulse driven

Single pulse driven (SPD)

Merits of SPD for HEC-RF application

- **Without high-current pre-ionization process**
  - **- The gas discharge time is shortened from tens of ms to hundreds of ns.**
  - **- Spotting optical elements, due to cathode sputtering, is reduced.**
  - **- The heat deposition in crystal, heated by cathodes, is reduced.**
- **The SPD mode is more suitable for rf application.**

Drawbacks of SPD for HEC-RF application

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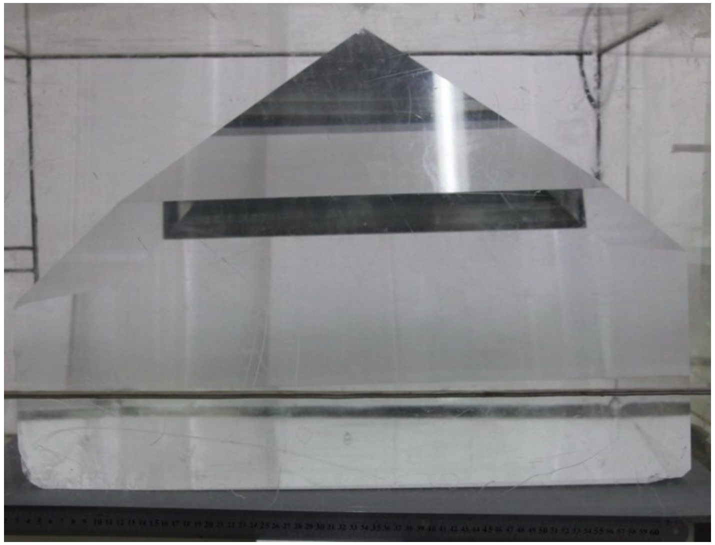


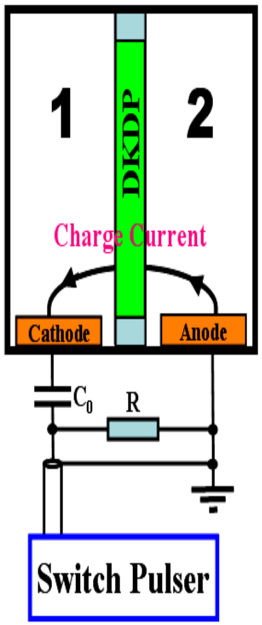
- KDP, DKDP is only available EO crystal which meets requirement of large-dimensions.
- DKDP, with a lower absorption coefficient (~0.2%cm^{-1}) than that of KDP (5%cm^{-1}), is the best choice at present.

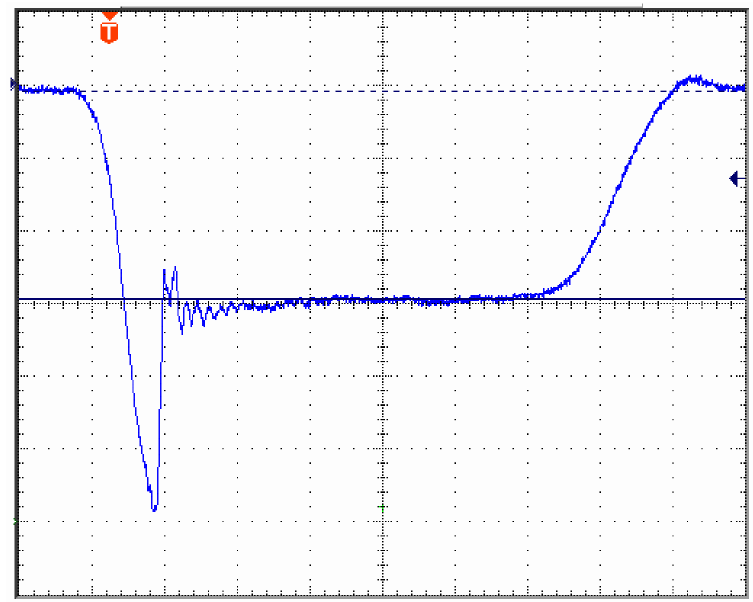
Drawbacks of SPD for HEC-RF application

However,

- The needed voltage to breakdown the gas ≥12 kV, so SPD PEPC generally uses KDP as electro-optic crystal because of its high half-wave voltage.
- The half-wave voltage of DKDP is ~6.8 kV, that is too low to realize single pulse driven PEPC.

Capacitance dividing voltage method for SPD DKDP PEPC

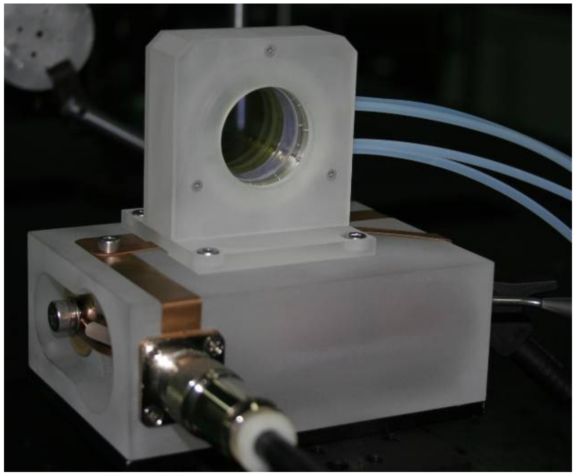




- A dividing capacitor is arranged in the circuit.
- Appropriate C_o and U makes that SPD DKDP PEPC works.

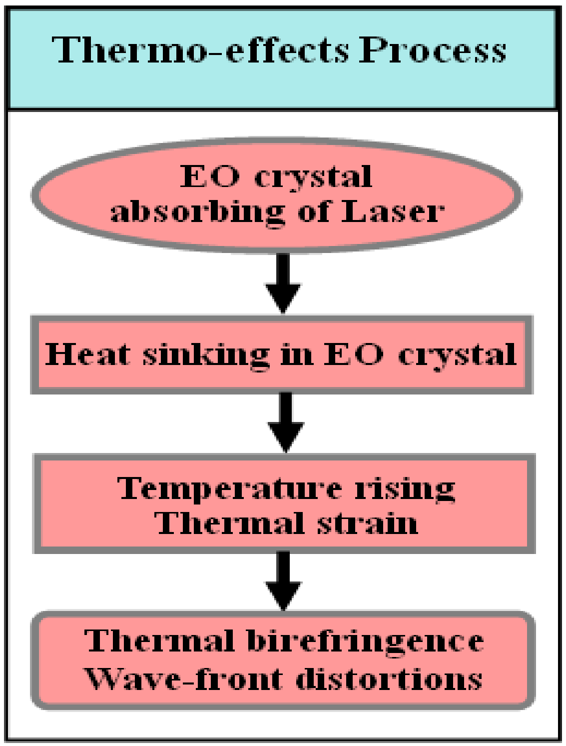
A single pulse driven DKDP PEPC

- A PEPC is fabricated to examine this scheme
- ~ 10^5 shots operating shows no degrading of transmission rate.
- Neither depolarization loss is observed in 2h continuous operating.



Parameter	Performance
Clear aperture: φ30mm	Rising time： 9.8ns
DKDP thickness: 3mm	Rep. rate： 10Hz
Driving voltage: ＜15kV	Insertion loss： 98.6%
Extinction ratio: ＞10^3： 1	Switching efficiency： ~99.5%

Thermo-effects arising from DKDP absorption of laser



- Even though DKDP has a lower absorption coefficient, thermo-effects is remarkable.
- Optical switch is sensitive to thermo induced birefringence.
- The deposited heat must be removed in time.

Heat convection coefficient of operating gas

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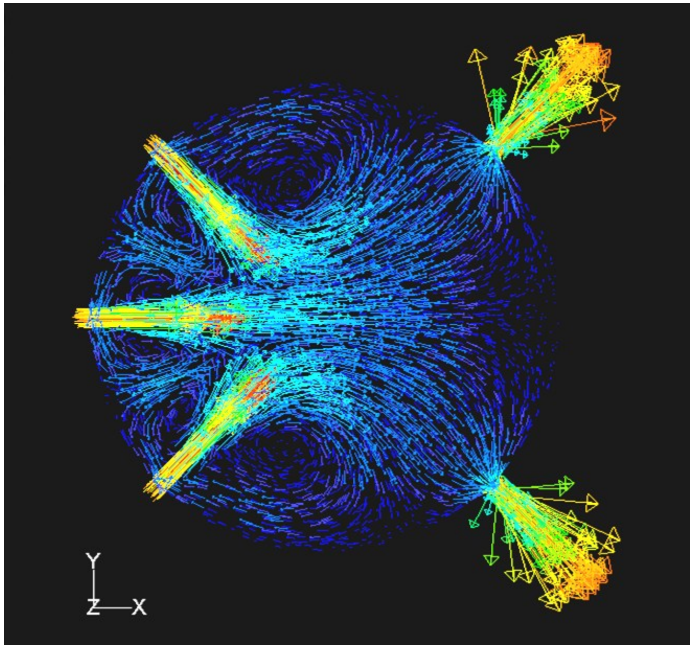
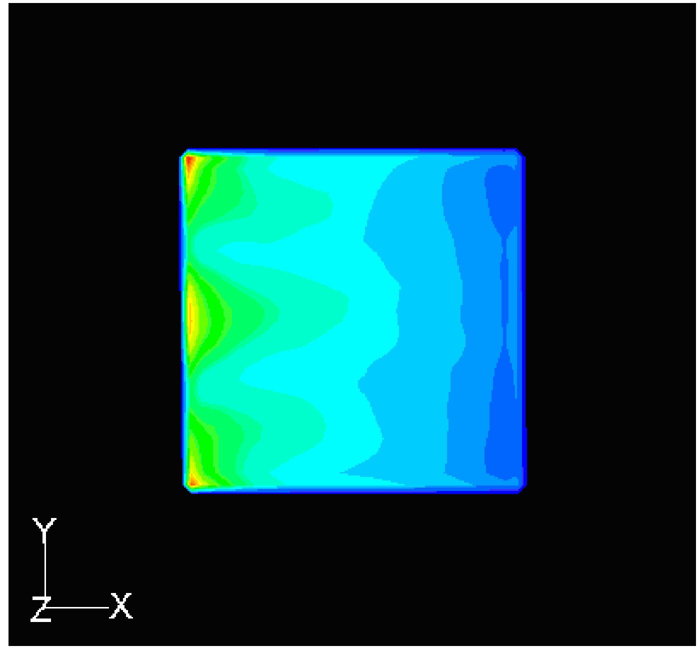
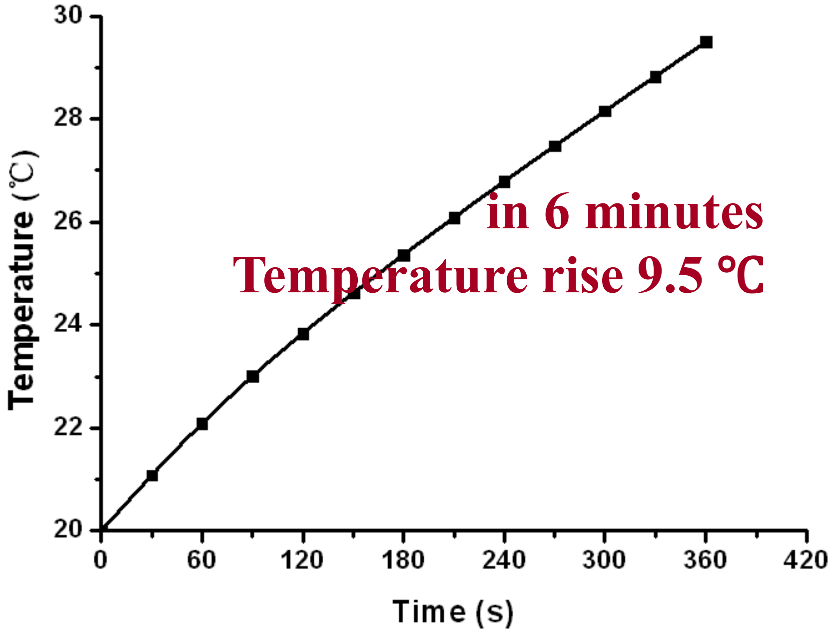


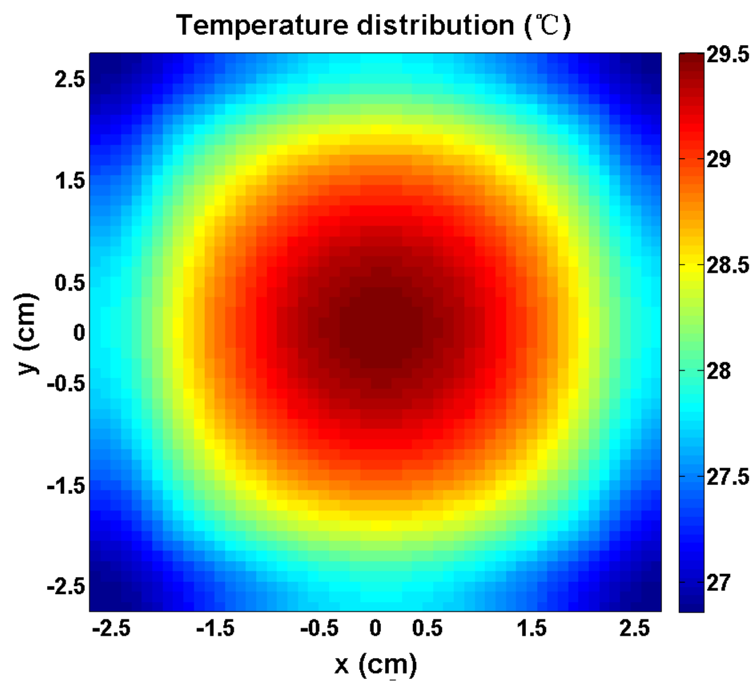


- Optimizing gas-flow distribution and heat convection coefficient by CFD
- Unfortunately, low operating pressure results in a h_c of ~10^{-4} W/cm^{2}K.
- This h_c is too small to efficiently remove the deposited heat in crystal.

Quantitatively describing of thermo-effects

Supposing the laser average power intensity is 30 W/cm^2





Demonstrating of the reflective PEPC concept

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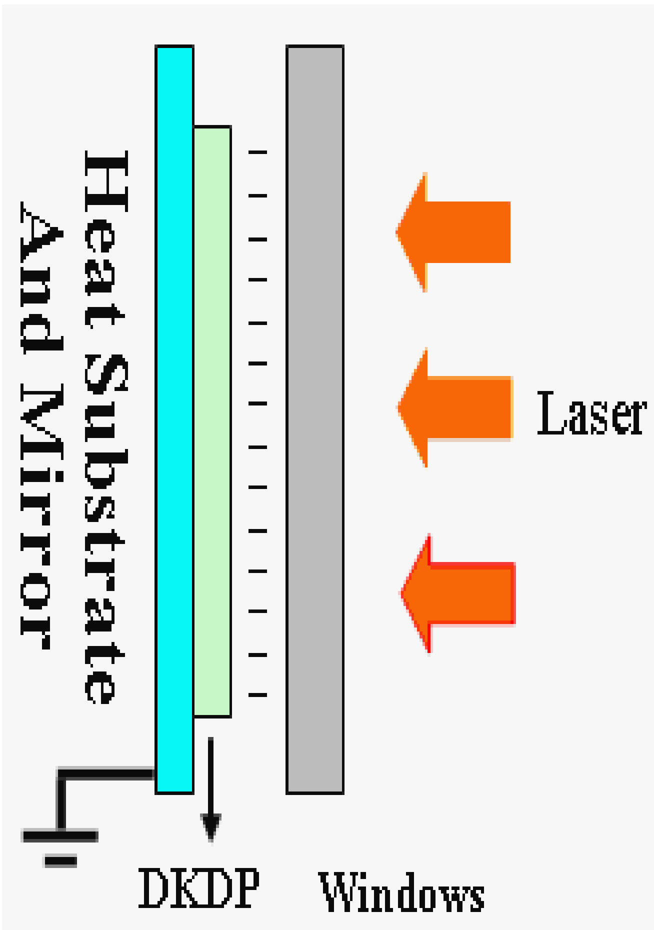
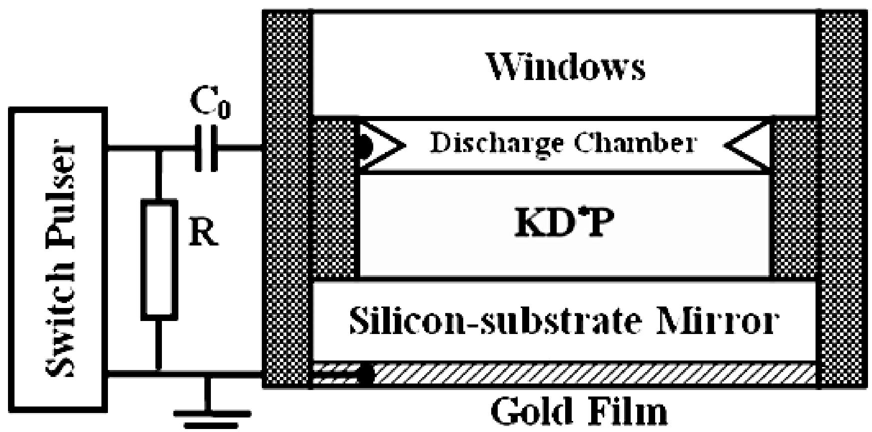
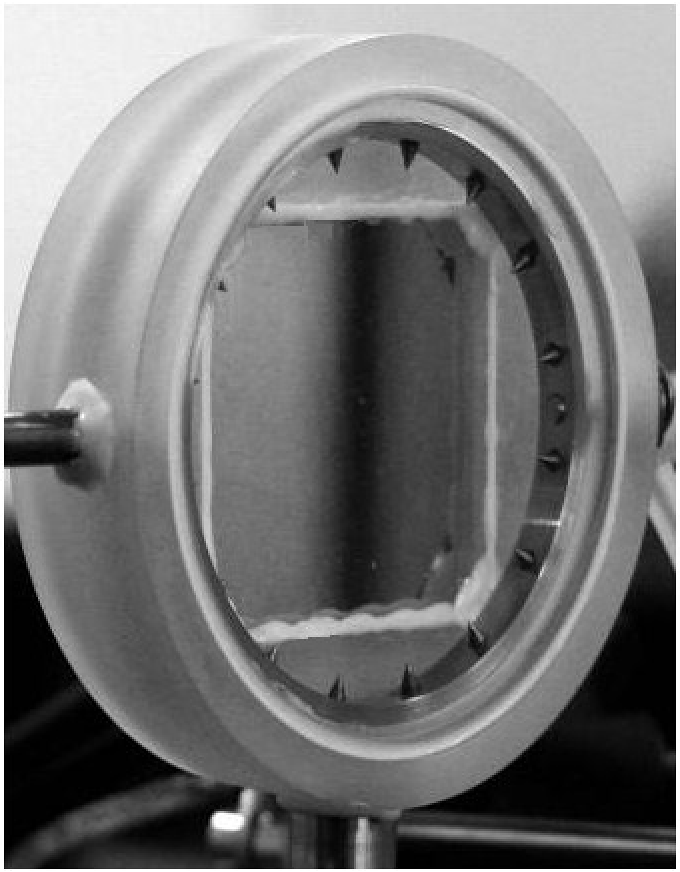


DKDP is longitudinally cooled

- Short heat-flux path-length
- large heat transfer area
- High cooling efficiency
- Small transverse temperature gradients



A reflective PEPC prototype

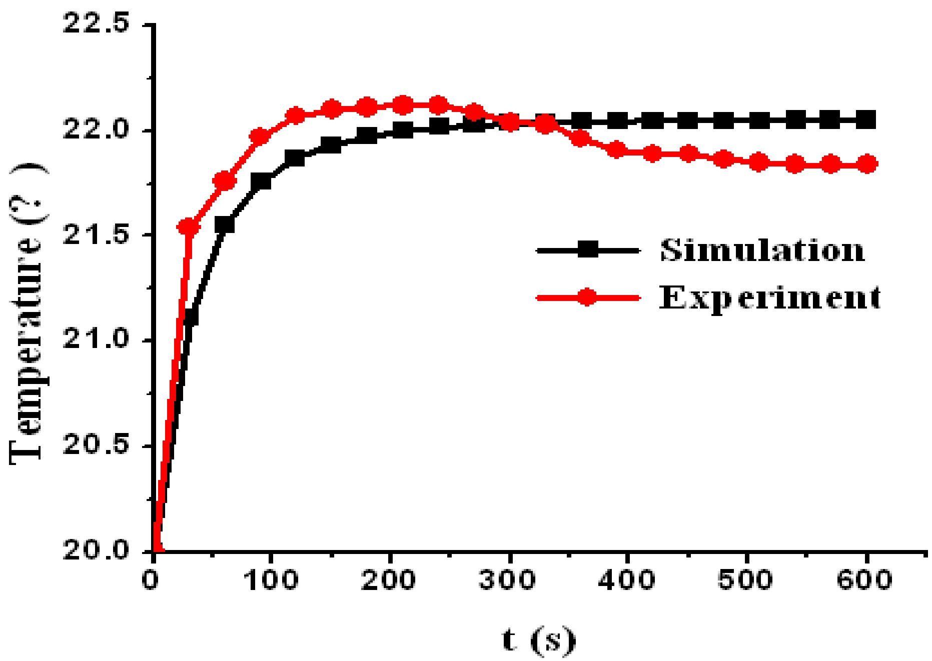


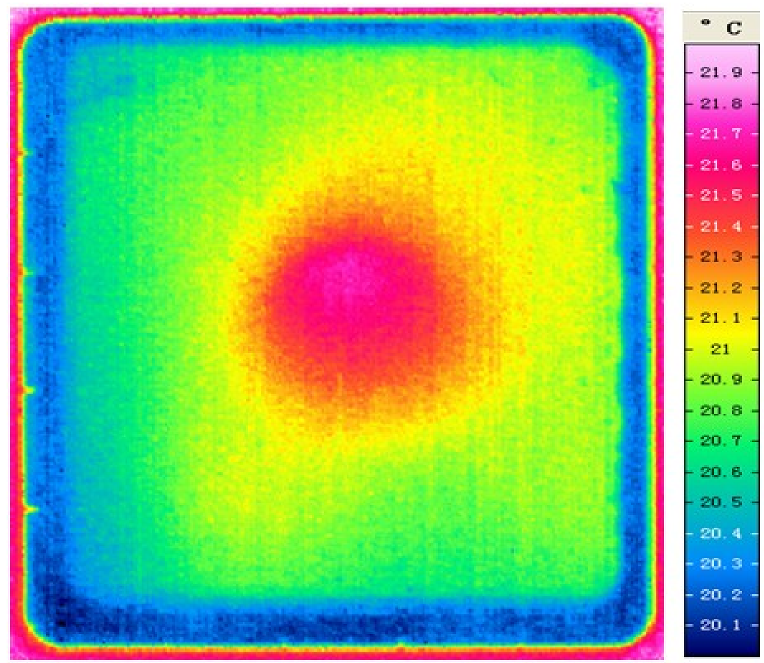
"Cold" performances not changing

Parameter	Performance
clear aperture	40mm×40mm
Extinction ratio	~1000:1
Switching efficiency	99.6%
Driving voltage	12.5 kV
Rising time	11 ns
Shot-to-shot jitter	10 ns (mainly from driver)

Thermal resistivity between DKDP and heat sink

- Heating source: 980 nm laser, 50 W/cm^2, beam aperture Φ20mm
- Measured thermal resistivity: around 65 cm^{2}K/W





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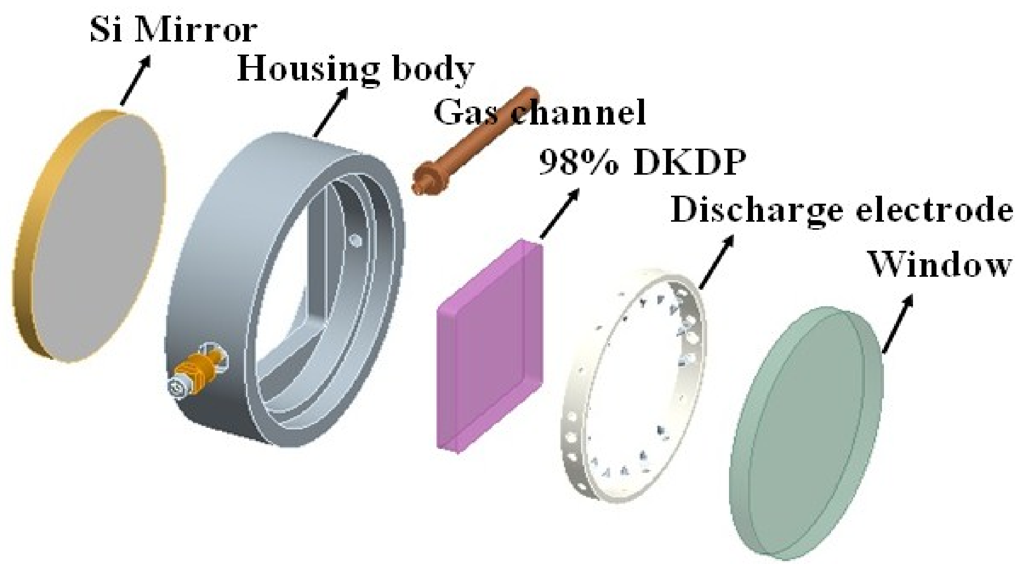

Output fluence is 5 J/cm²

For 100 J/10 Hz application

Clear aperture: 45mm×45mm

- DKDP: 55mm×55mm×6mm
- Si Mirror: Φ80mm×8mm
- Matching impedance： 12.5 ohm
- Plasma Chamber: Φ80mm×8mm
- Insertion loss: 1.5%
- theory rising time: 2.5 ns
- Driving voltage: 15.5 kV

Predicted "hot" performances

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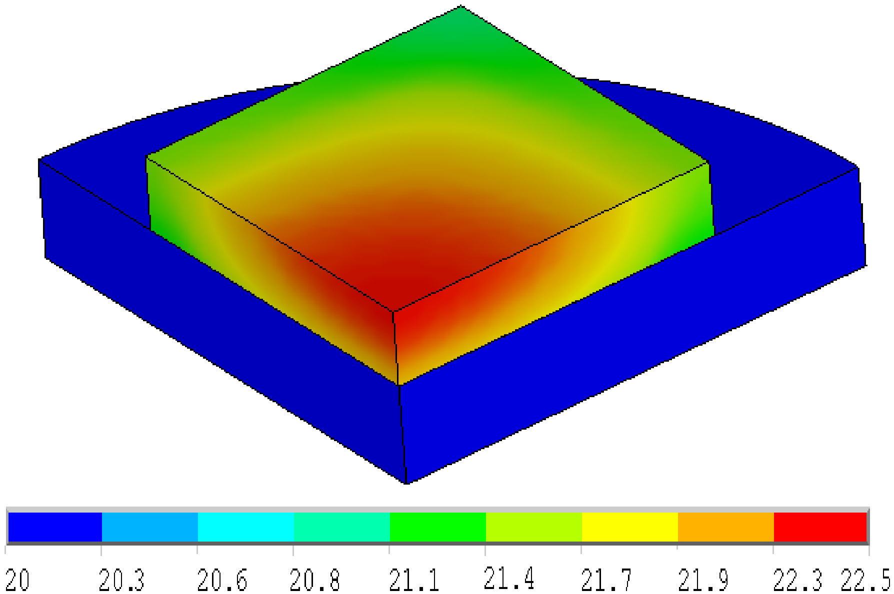

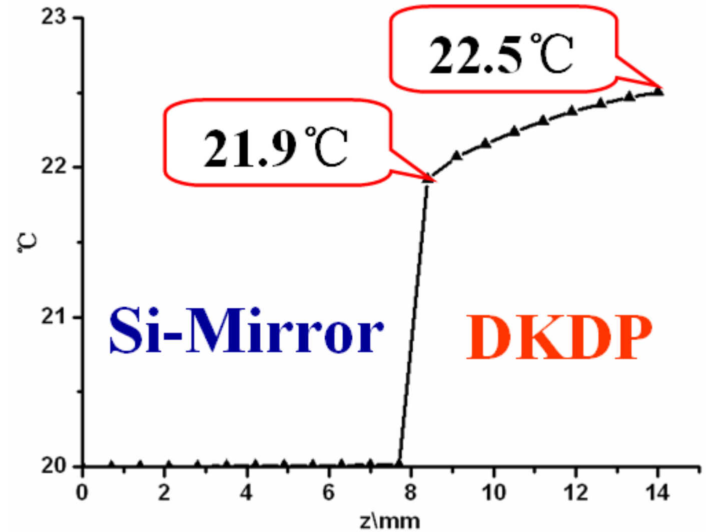

- At thermal steady-state, max temperature rise in DKDP is 2.5 °C， whereas temperature difference is 0.6 °C
- There is a temperature drop of 1.8 °C between DKDP and Si-mirror contact surfaces due to contact thermal resistivity.

Depolarization & wavefront distortion

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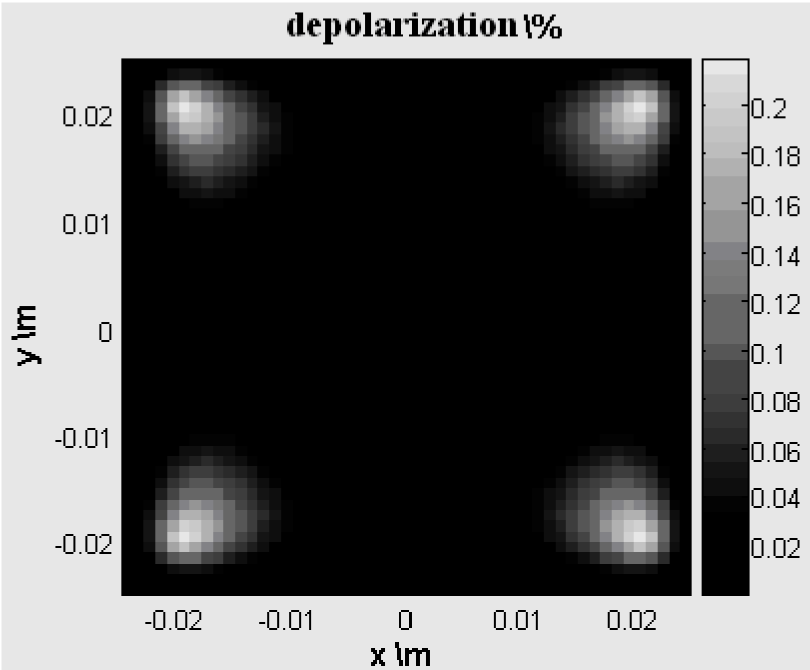

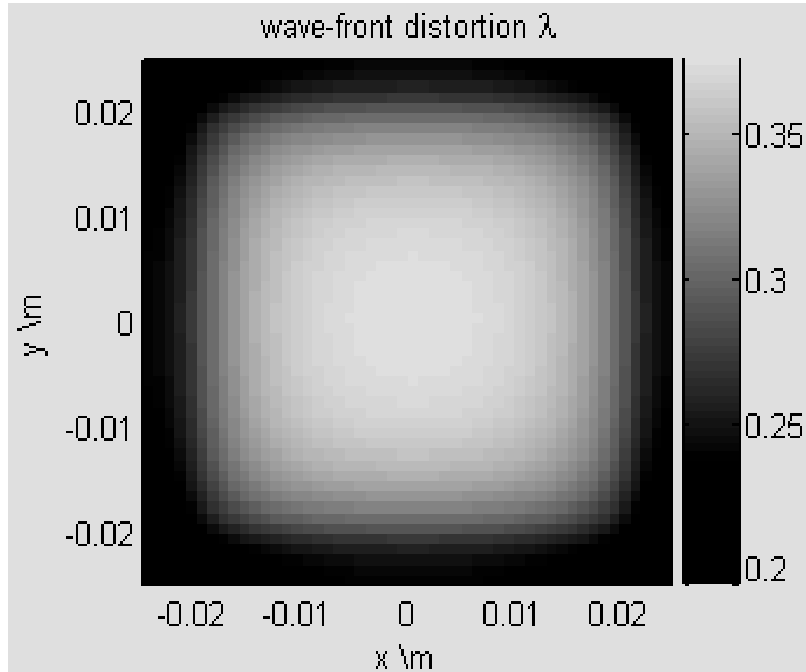

- Maximal depolarization: 0.22%, located at corners of the laser beam
- Average depolarization: 0.02%, over the laser beam
- Wavefront distortion: 0.18 λ (λ=1030 nm)

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Summary

- We introduce challenges that PEPC encounters for HEC-rf application
  - One single pulse driven DKDP PEPC
  - Thermo-effects
- and their tactics are demonstrated.
  - Capacitance dividing voltage method
  - Reflective design and conduction-cooling
- At last, we present the design of a R-PEPC for 100J/10Hz amplifier application, and its performances are discussed.


Thanks for your attention!