Ultra-Broadband Optical Parametric Chirped Pulse Amplification with Partially Deuterated KDP Crystal

Junji Kawanaka, Hwang Sungln, Koji Tsubakimoto,
Kana Fujioka, Yasushi Fujimoto, and Noriaki Miyanaga

Institute of Laser Engineering (ILE), Osaka University

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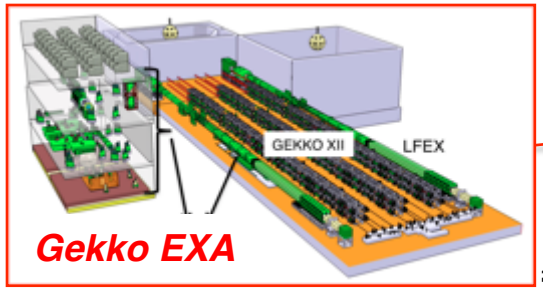
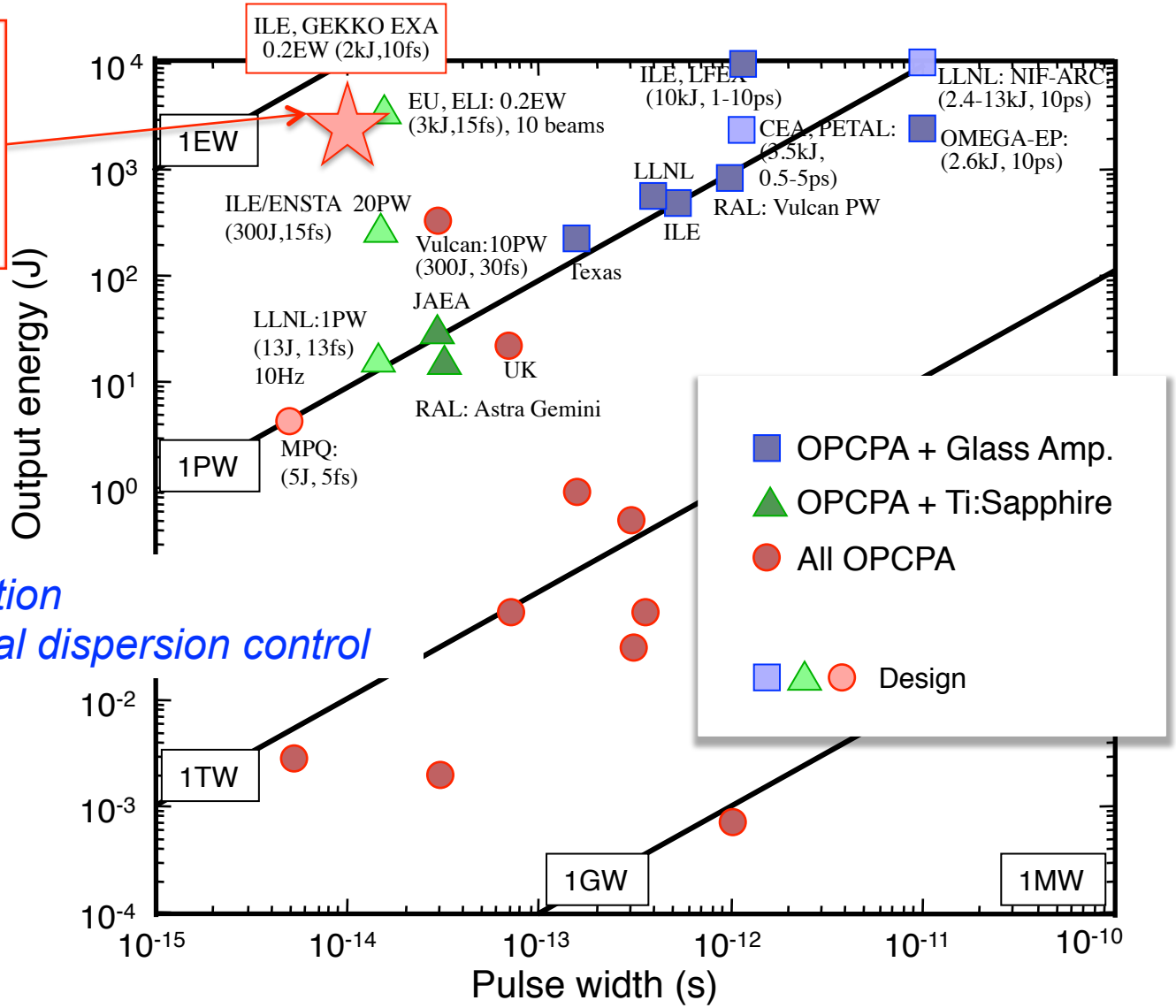
Ultra-intense lasers over the world



✓ Sub-EW
✓ Few cycle

☀ *Broadband amplification*
☀ *Temporal and spectral dispersion control*



Outline

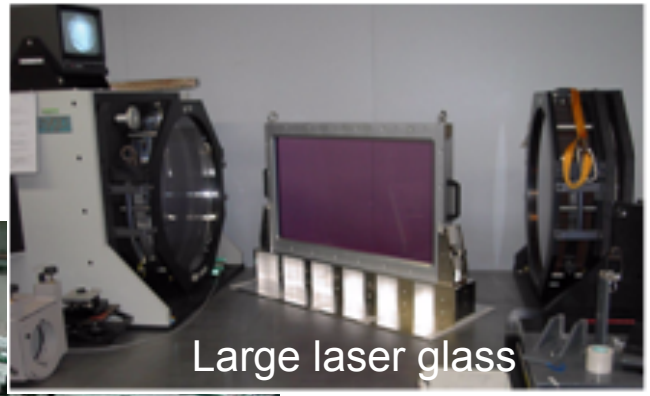
1. **Arrayed-Beam Pumped OPA** for kilo-joule

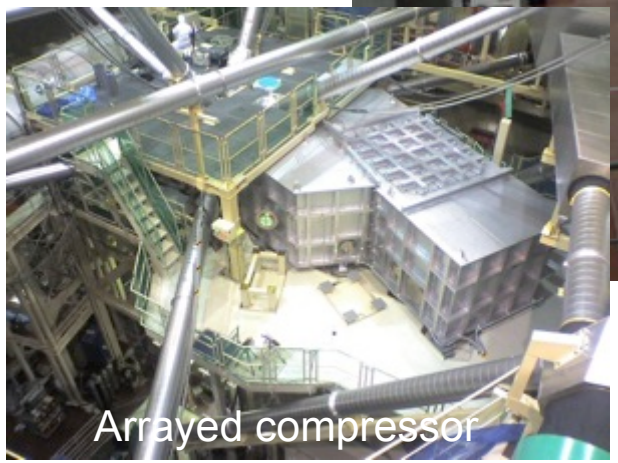
2. **Partially Deuterated KDP**
   - 2-1 Broadband OPA Gain
   - 2-2 Crystal Growth

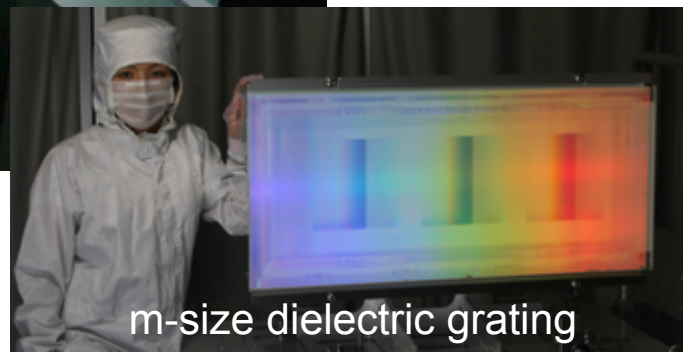
3. **Broadband Dielectric Grating**
   - 3-1 Groove Structure and Material

Arrayed Beam Pumped OPA for kilo-joule

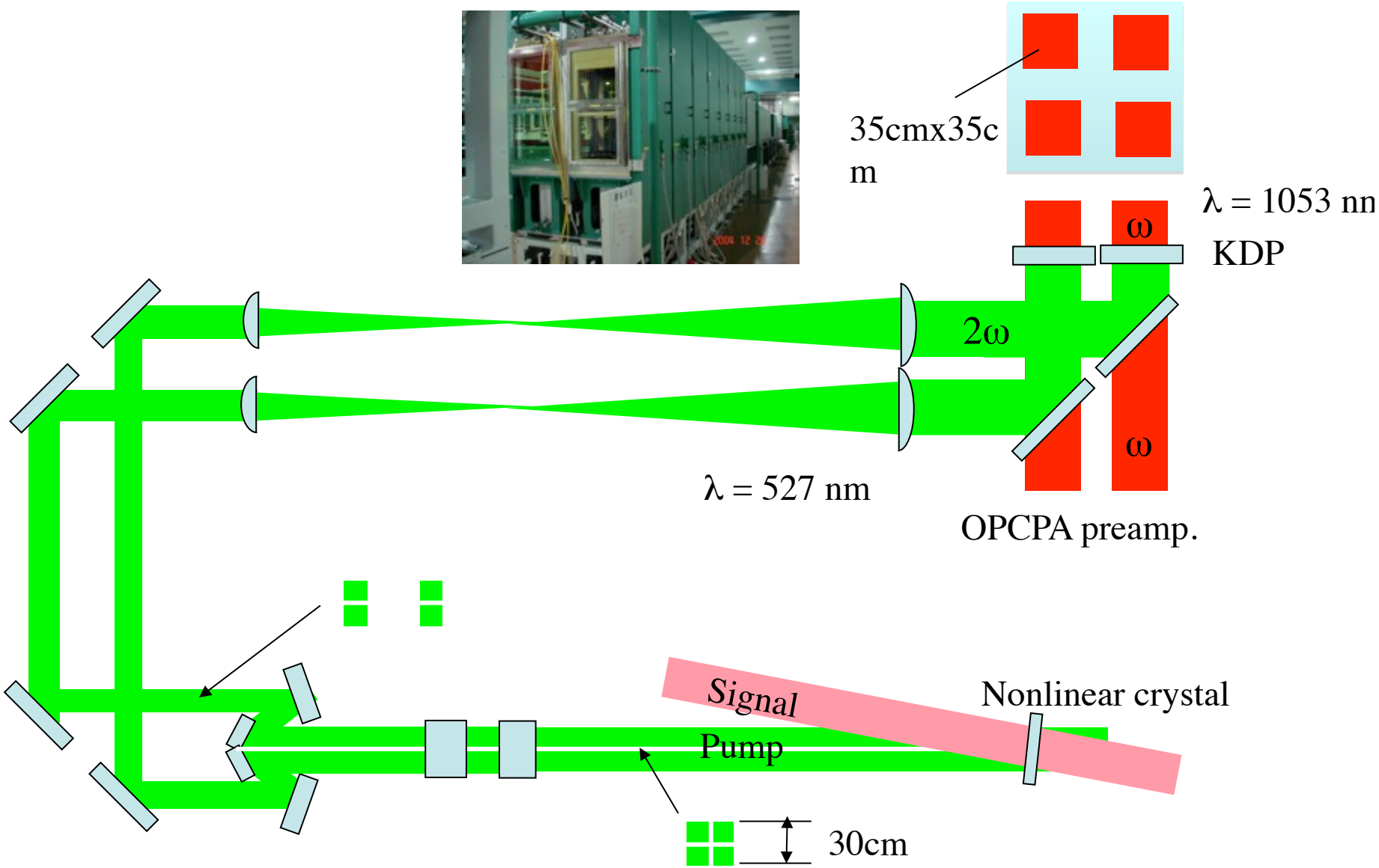
kJ-pump source based on LFEX-Laser technologies



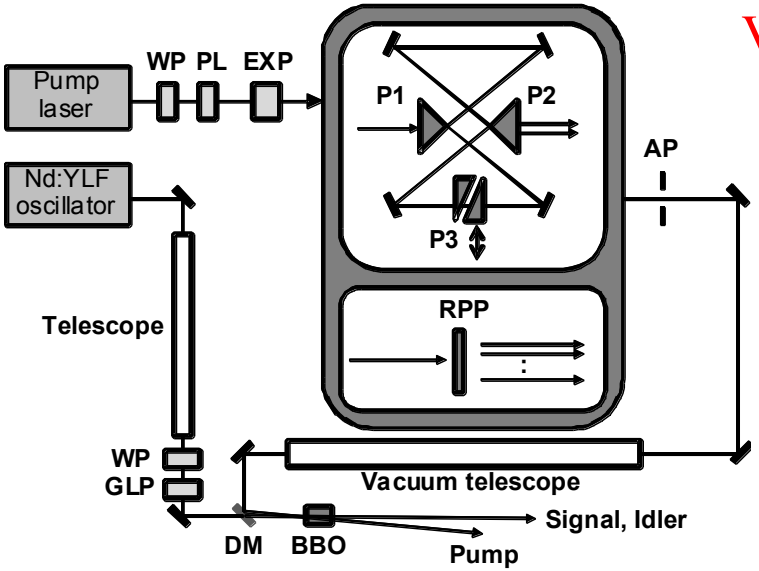




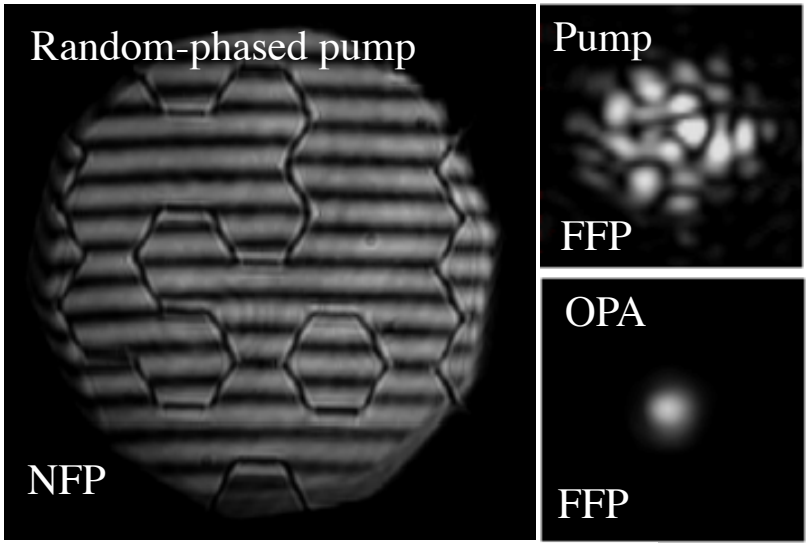
Large-aperture OPCPA pumped by arrayed beams

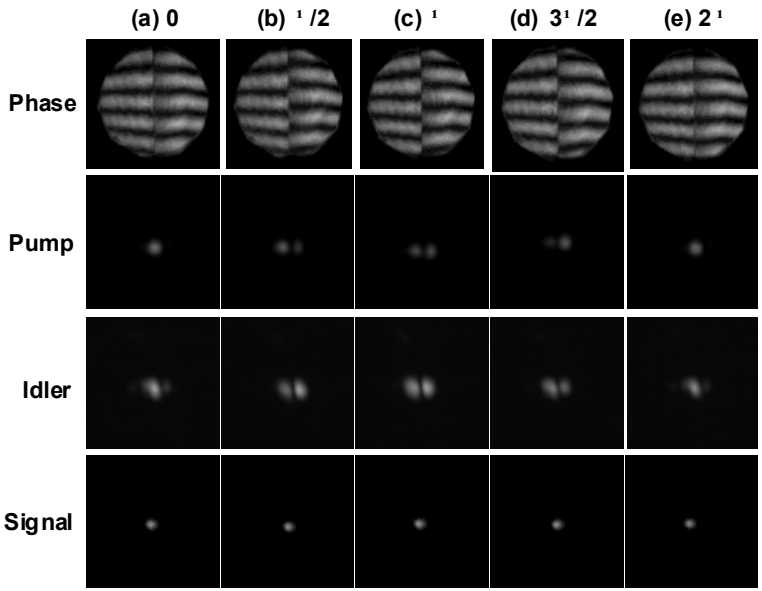


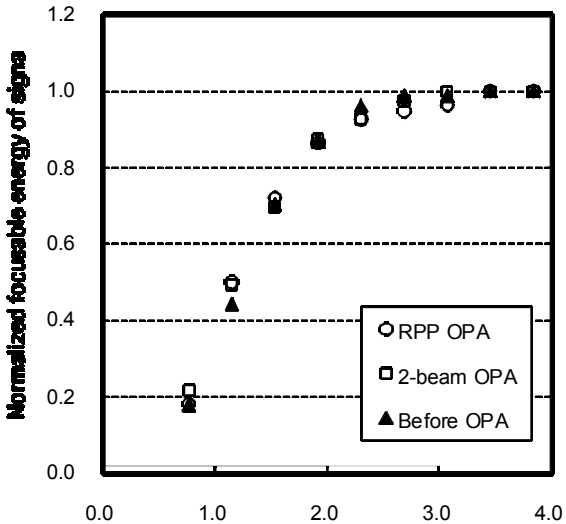
Proof-of-principle of OPA with random-phased pump



Virtually alignment free for beam combination ?



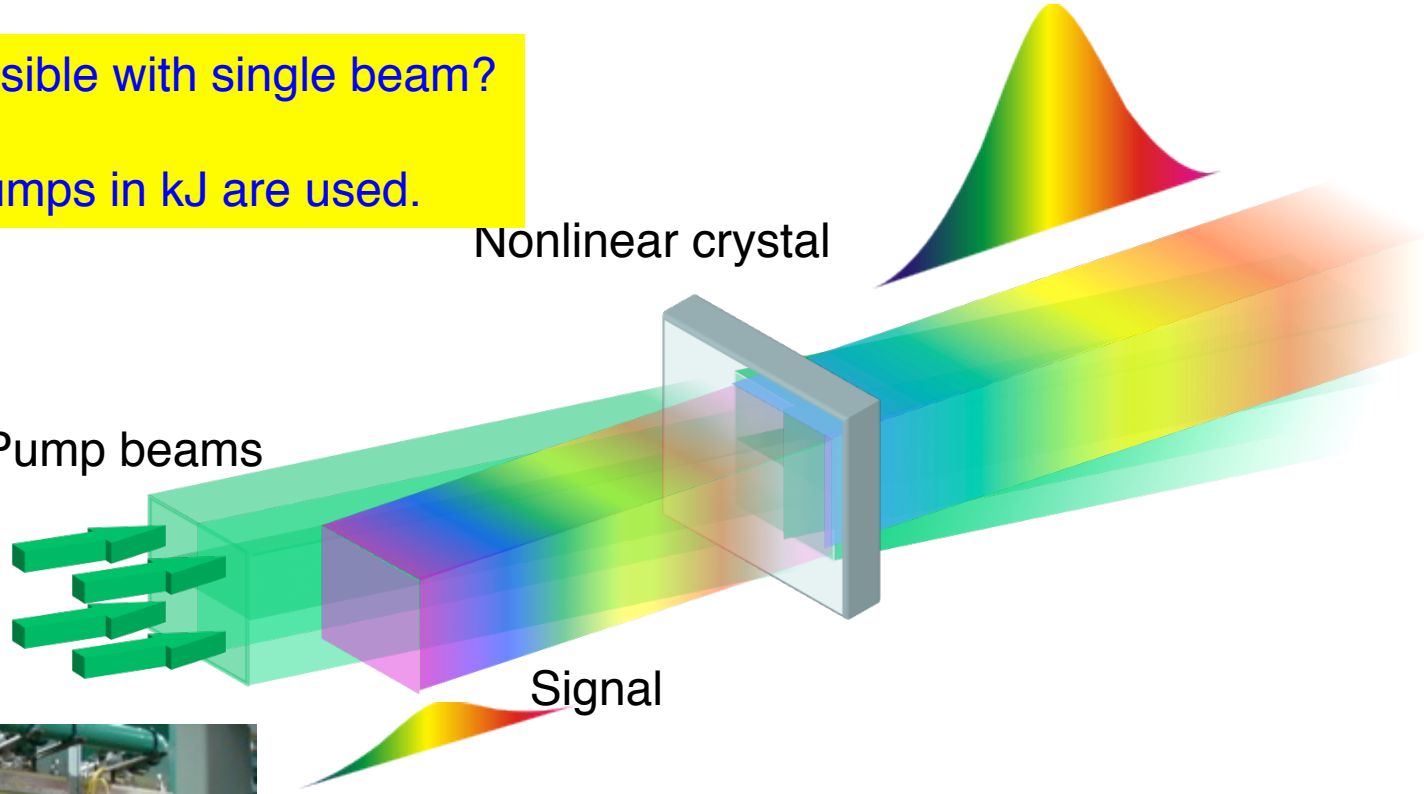




Large-aperture, ultra-broadband OPCPA with arrayed pumps

Is 100PW feasible with single beam?

→ Arrayed pumps in kJ are used.



Partially Deuterated KDP (p-DKDP)

Sellmeier eqations of p-DKDP

p-DKDP Sellmeier equations by using KDP and DKDP,

(1) V. V. Lozhkarev, G. I. Freidman, V. N. Ginzburg, E. A. Khazanov, O. V. Palashov, A. M. Sergeev, and I. V. Yakovlev, "Study of broadband optical parameteric chirped pulse amplification in a DKDP crystal pumped by the second harmonic of a Nd:YLF laser," Laser Phys. Vol. 15, No. 9 p.p. 1319-1333 (2005).

KDP and DKDP Sellmeier equations,

(2) Kevin W. Kirby and Larry G. DeShazer, "Refractive indices of 14 nonlinear crystal isomorphic to KH_2PO_4, JOSA B vol. **4**, No. 7 pp.1072-1078 (1987).

(3) Frits Zernike, Jr., "Refractive indices of Ammonium Dihydrogen Phosphate and Potassium Dihydrogen Phosphate between 2000 A and 1.5μ", JOSA vol. **54**, No. 10 pp. 1215-1220 (1964).

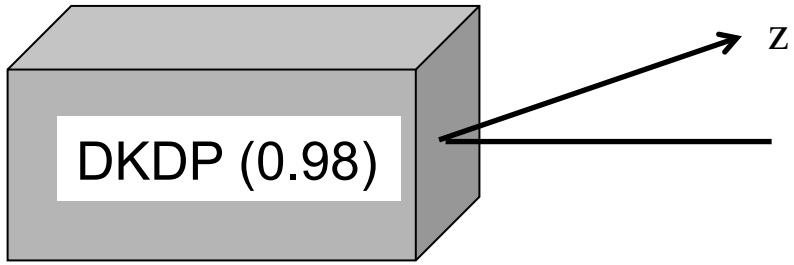
Temporal waveform in collinear OPCPA

Seed $\Delta\lambda$ = 300 nm @1030nm
CR = 1 nm/ps

Pump 515 nm

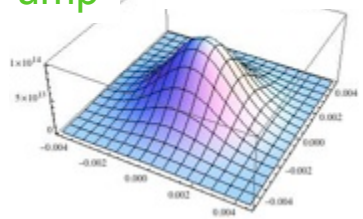
Gaussian in temporal and spatial

L=17mm

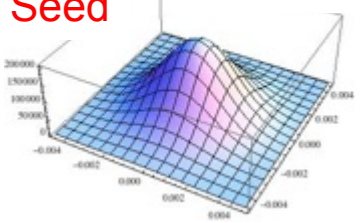


θ_{pm}=36.9143

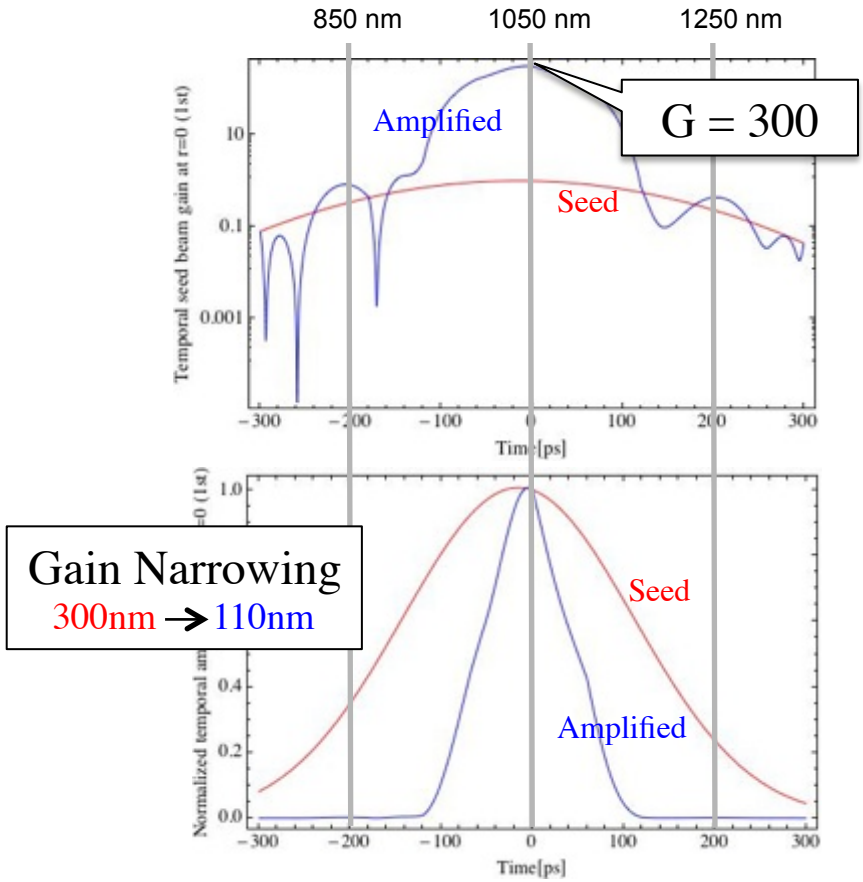
Pump 10 GW/cm^2



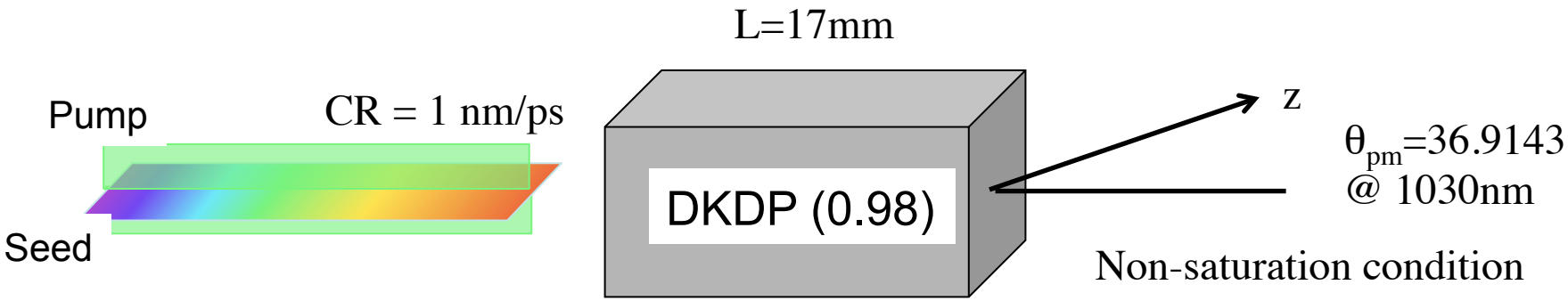
Seed 20 W/cm^2



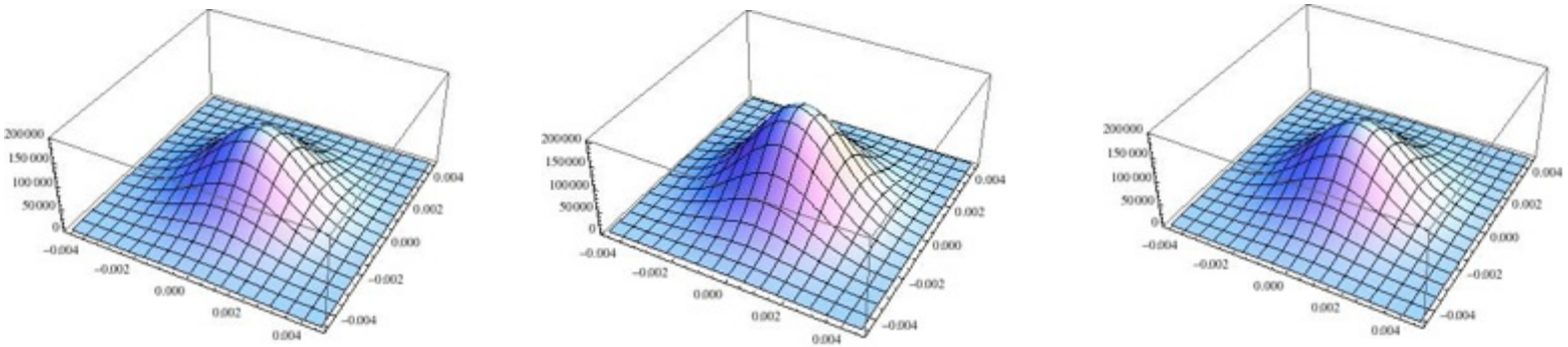
Non-gain-saturation



Temporal change of beam profile in collinear OPCPA



Seed

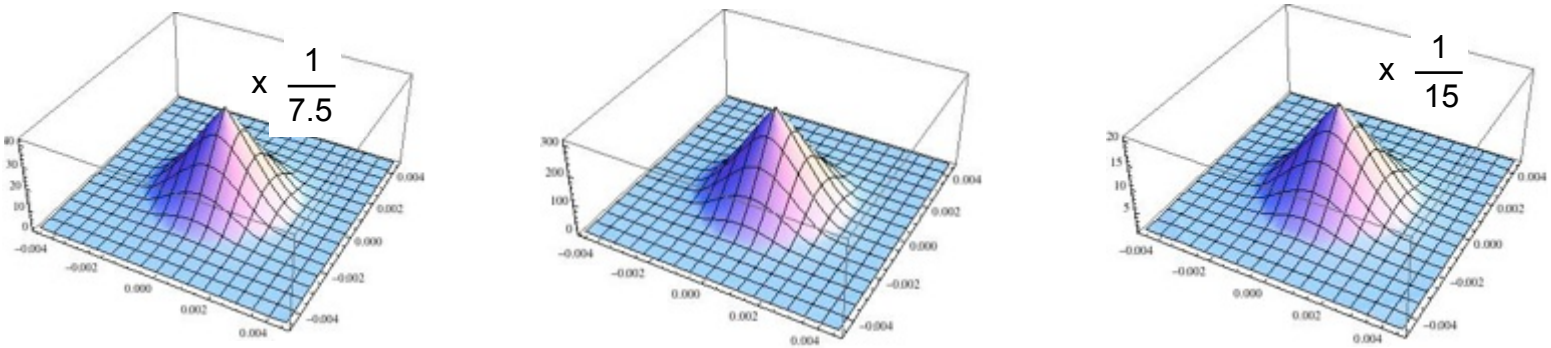


-100ps
(930nm)

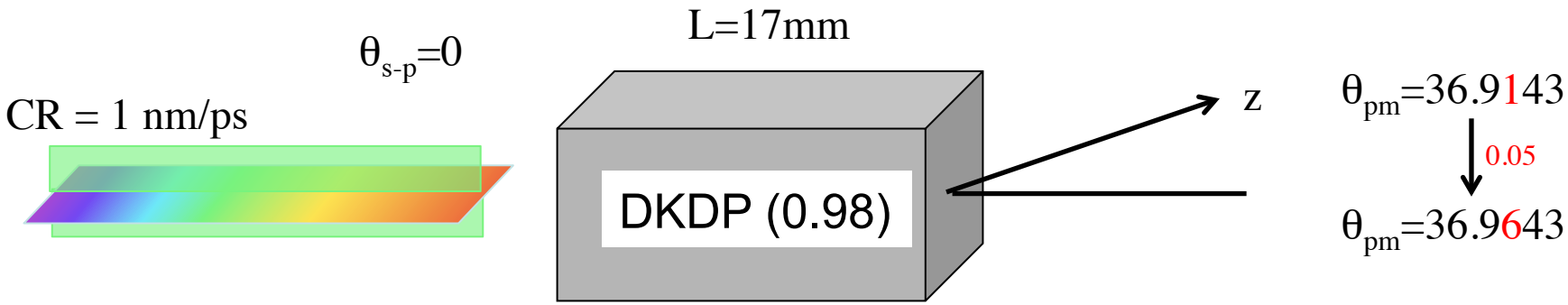
0ps
(1030nm)

+100ps
(1130nm)

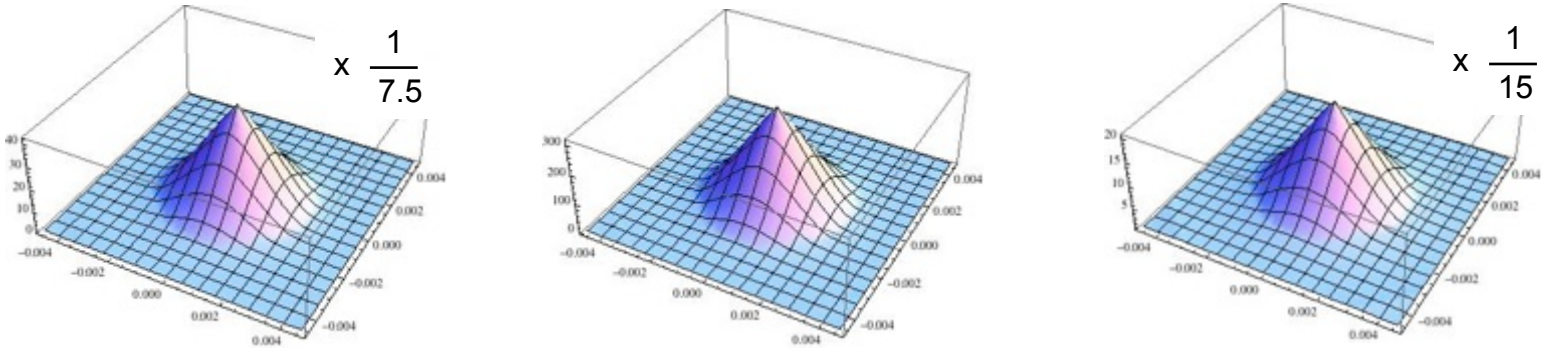
Amplified



Temporal change of beam profile in collinear OPCPA

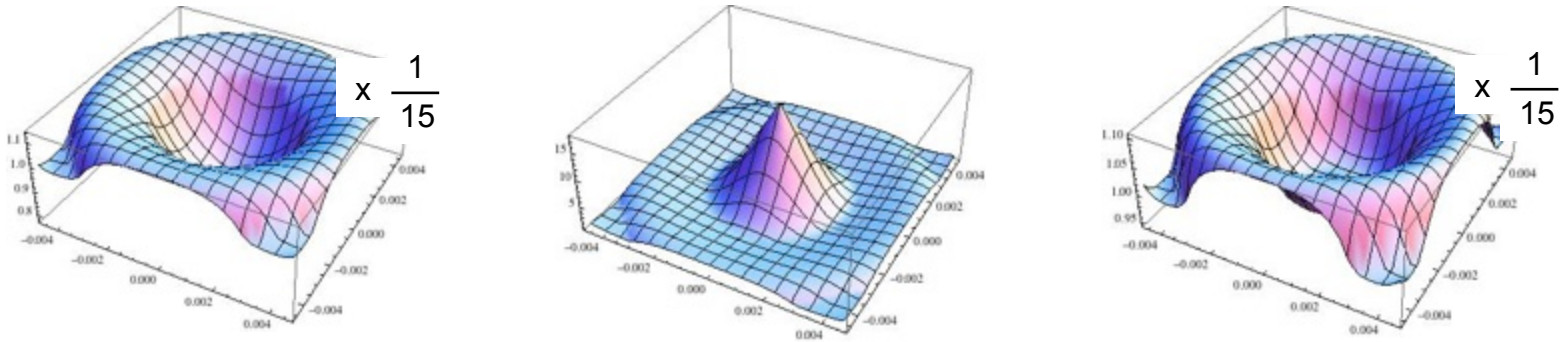


Phase Matching



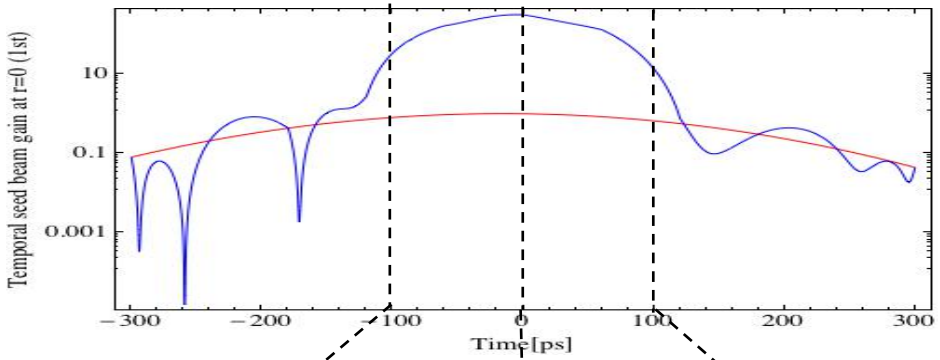
-100ps (930nm) | 0ps (1030nm) | +100ps (1130nm)

Non-Phase Matching



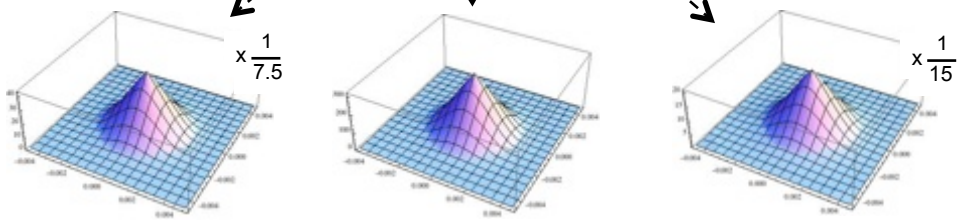
Gain bandwidth at off-phase-matching in collinear OPCPA

Phase Matching for λ_0 and $\lambda_{2\omega}$



Gain Narrowing
300nm → 110nm

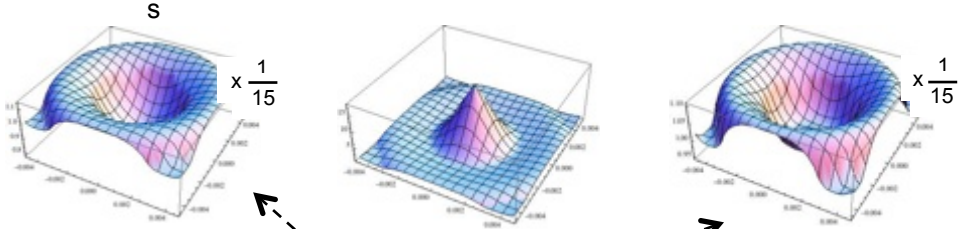
G_{peak} = 300



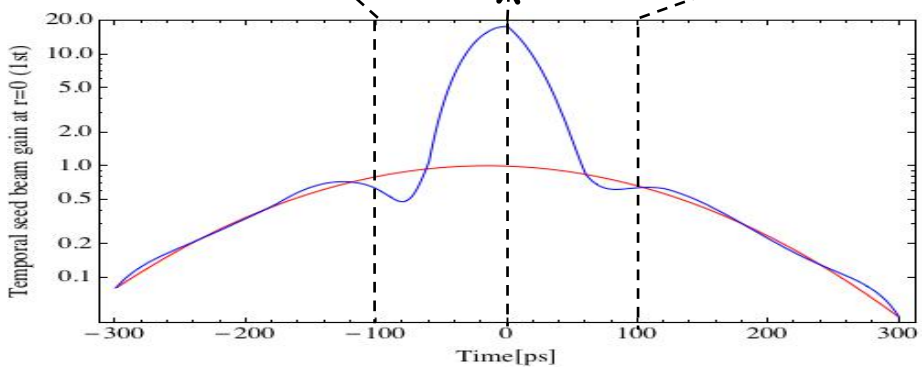
-100ps

0ps

+100ps



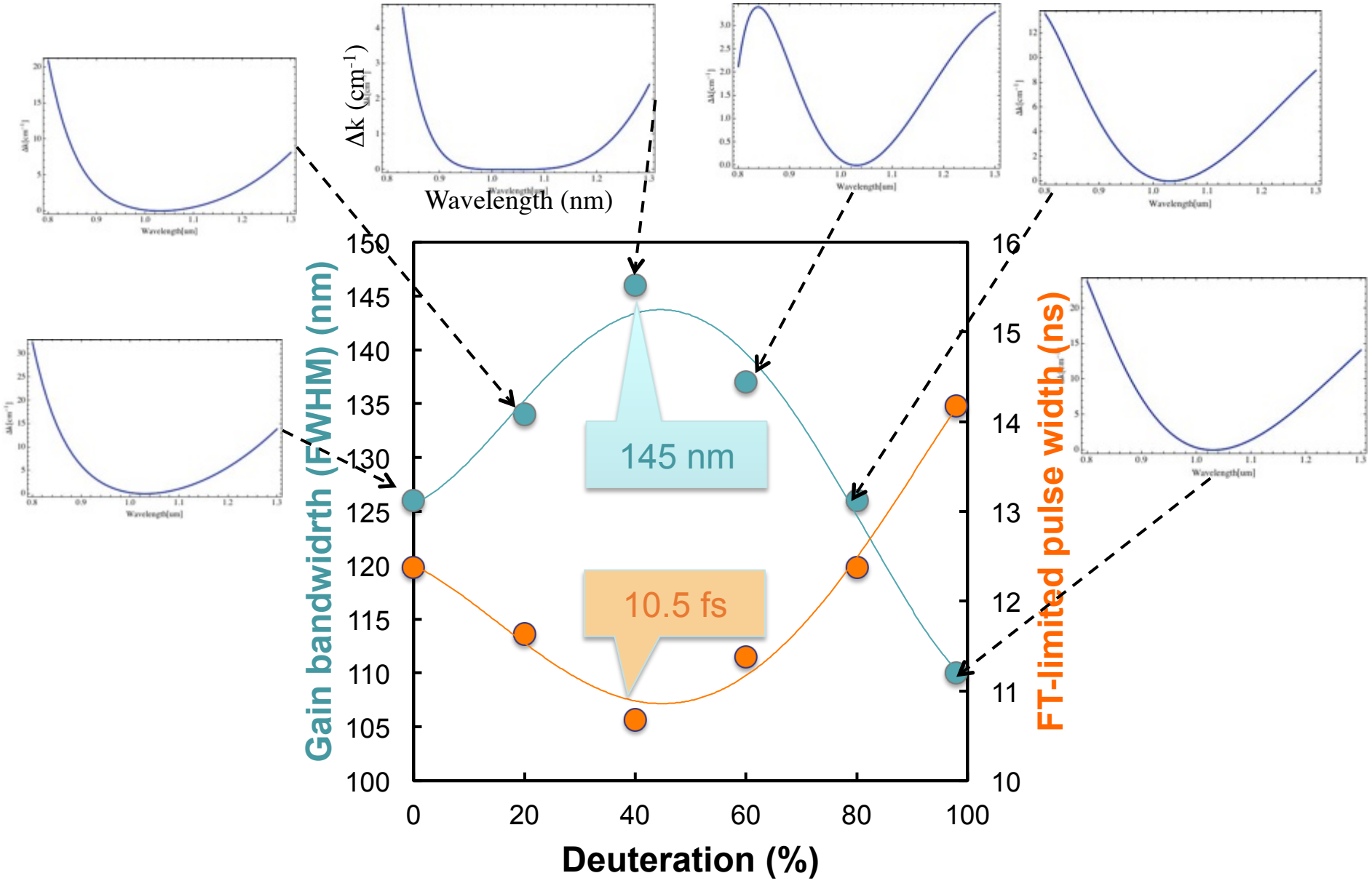
Non-Phase Matching for λ_0 and $\lambda_{2\omega}$



Gain Narrowing
300nm → 50nm

G_{peak} = 20

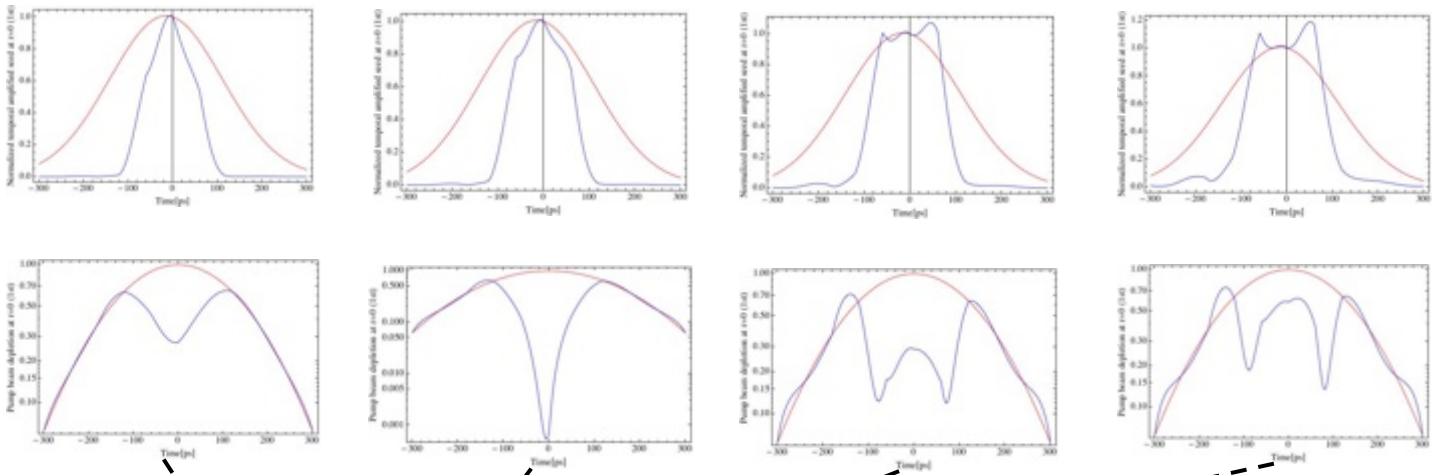
Deuteration dependence of gain bandwidth

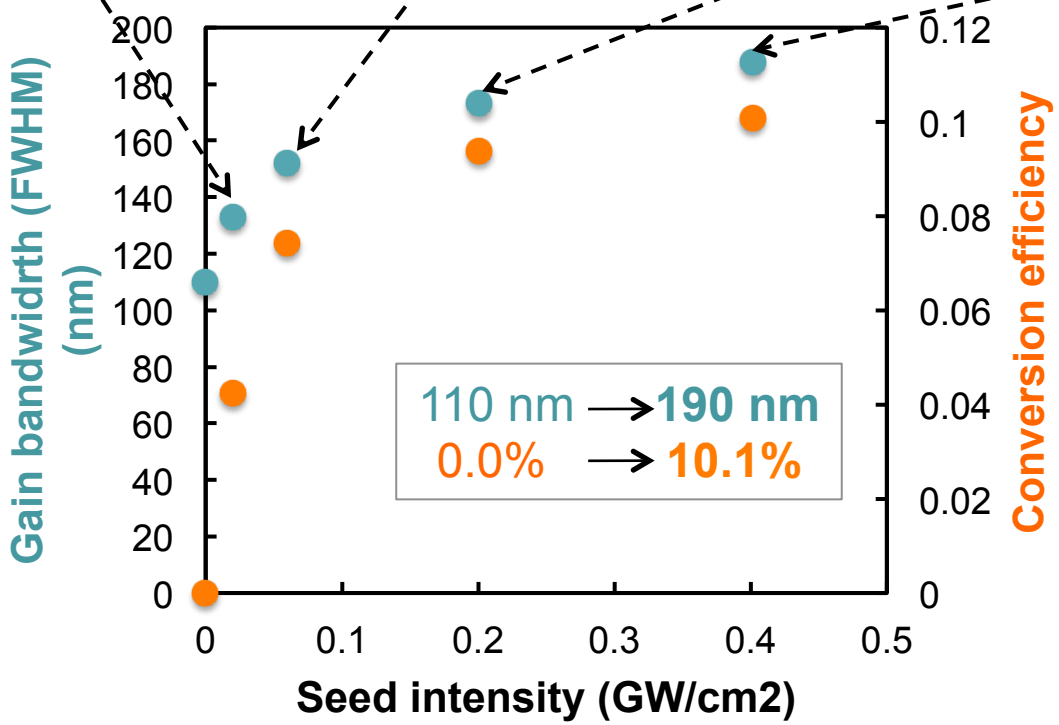


Gain bandwidth broadening due to gain saturation

Temporal profile
(Spectral profile)

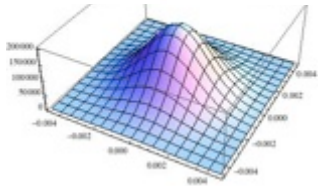
Pump beam
depletion

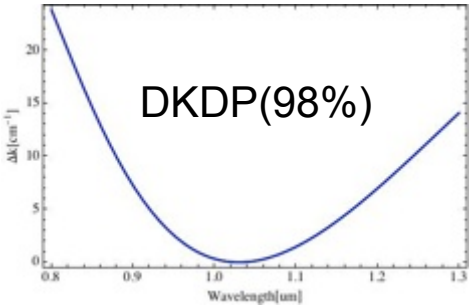




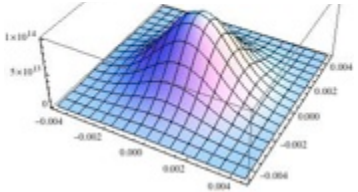
pDKDP(40%) + Gain Saturation in collinear OPCPA

Signal 20 W/cm^2

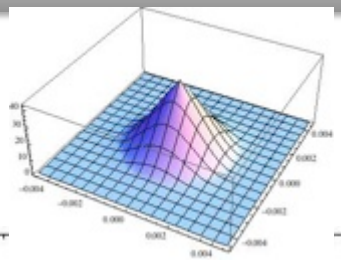


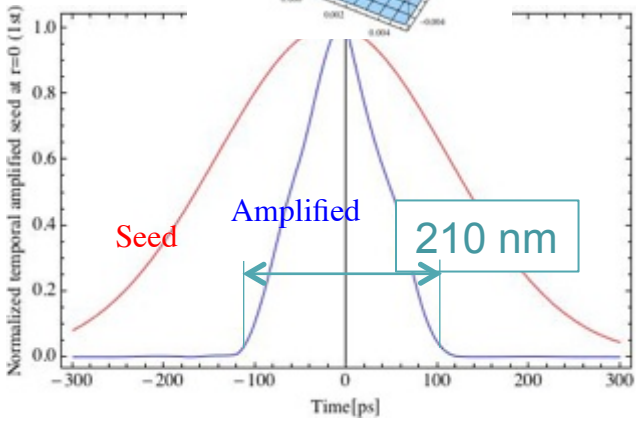


Pump 10 GW/cm^2

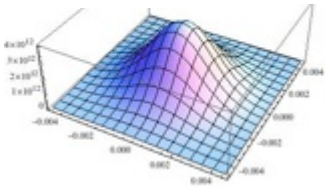


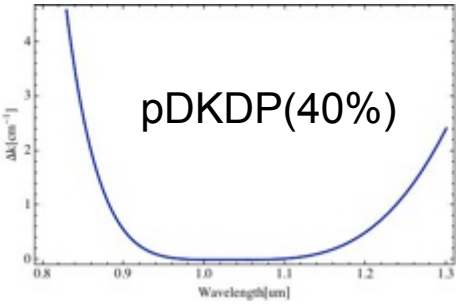
Amplified Signal



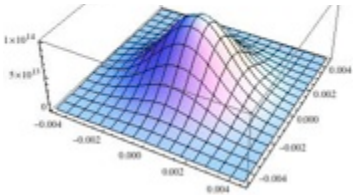


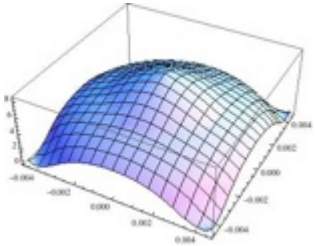
Signal 0.4 GW/cm^2

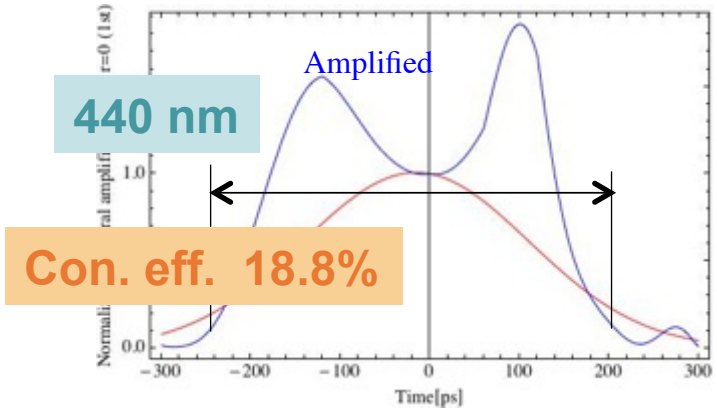




Pump 10 GW/cm^2



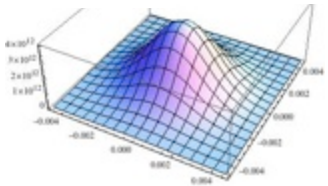




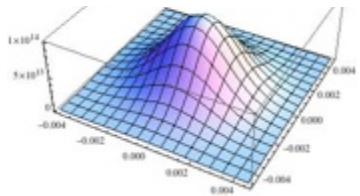
How about Non-collinear ? pDKDP(40%) + Gain Saturation

pDKDP(40%)

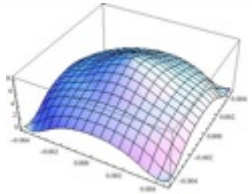
Signal 6 GW/cm^2



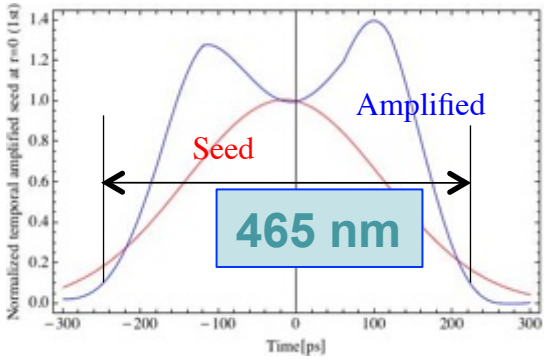
Pump 150 GW/cm^2



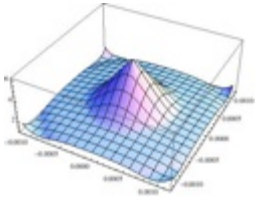
Collinear



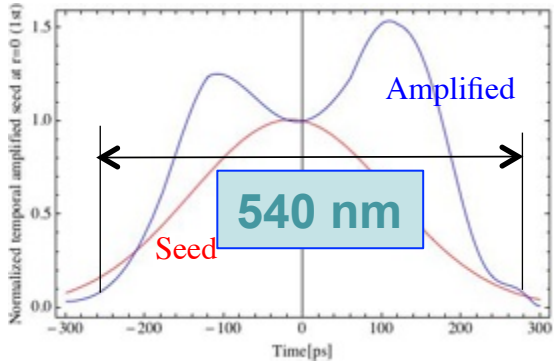
Con. eff. 18.8%



Non-Collinear



Con. eff. 8.0%



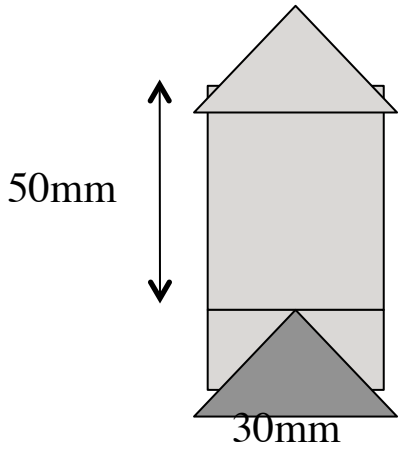
1) N-CL shows a broader gain bandwidth than CL.
2) Need higher pump intensity in N-CL to recover the reduced gain.
3) Also, need to take much care of the optically induced damage.

Crystal growth schedule of p-DKDP

2010 Check the previous parameters in crystal growth
Reconstruct the growth system

2011 Trial of crystal growth in cm-size
with deuteration between 50% and 80%
Storage procedure of the crystal

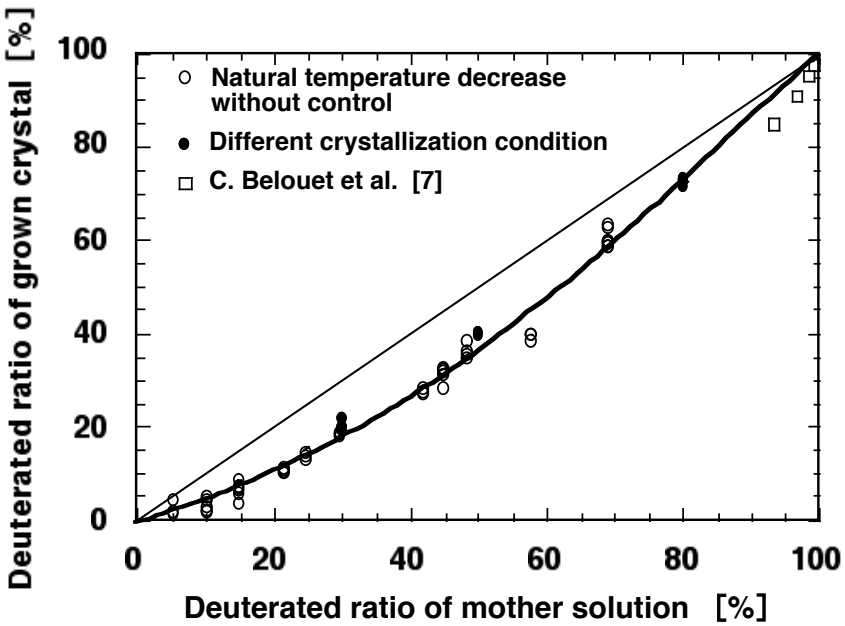
2012 Refractive index measurement (Sellmeier equations)

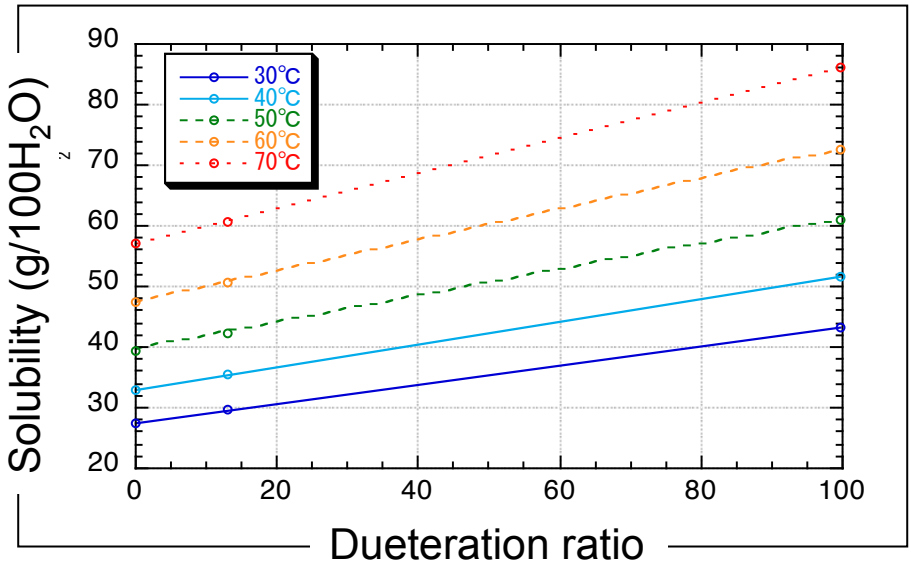


3-litter much mother solution to avoid segregation of dueterium

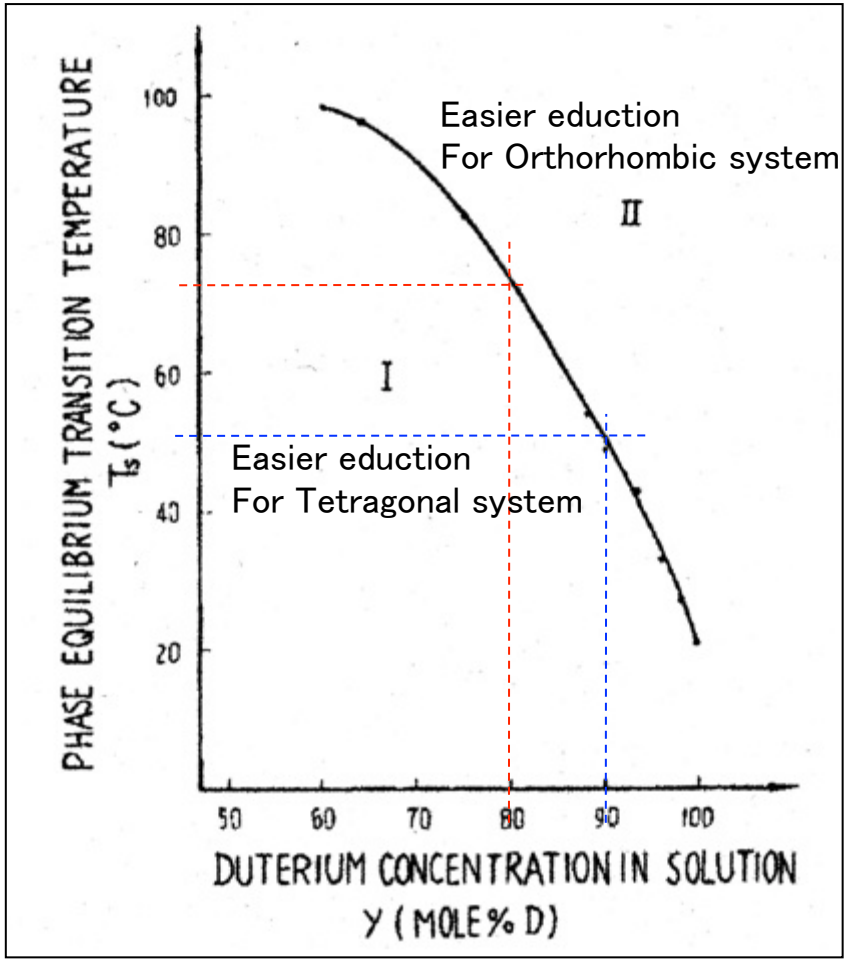
Growth
Capping:7days
Growth:33days (2mm/day)

Basic Data of p-DKDP Crystal Growth

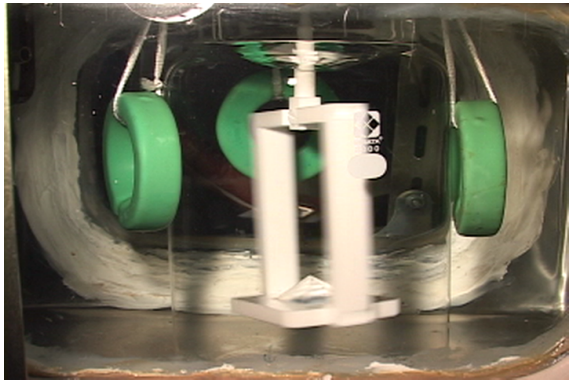


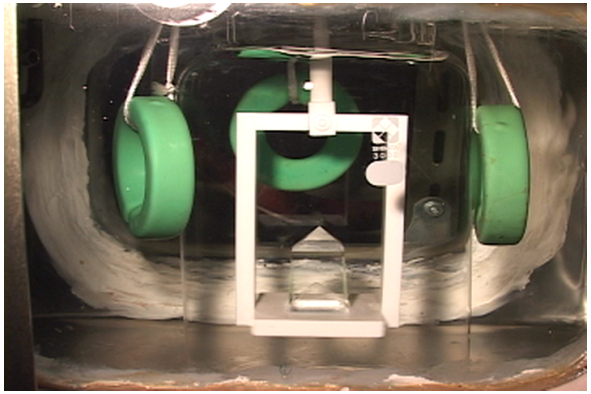


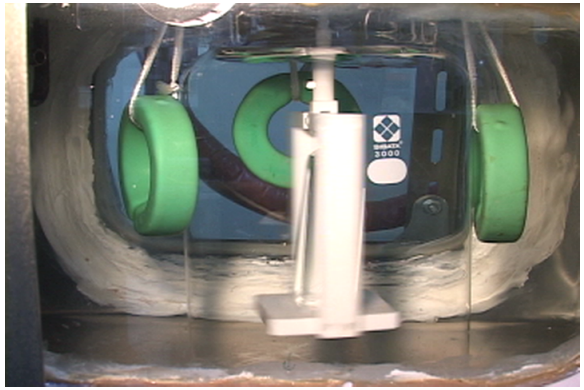
J. Crystal Growth, **53** (1981) 283.

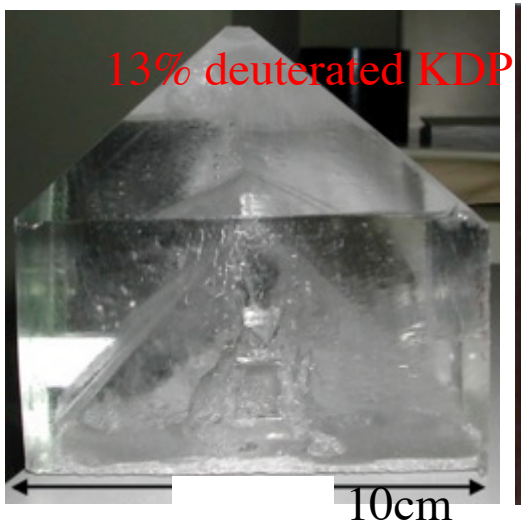


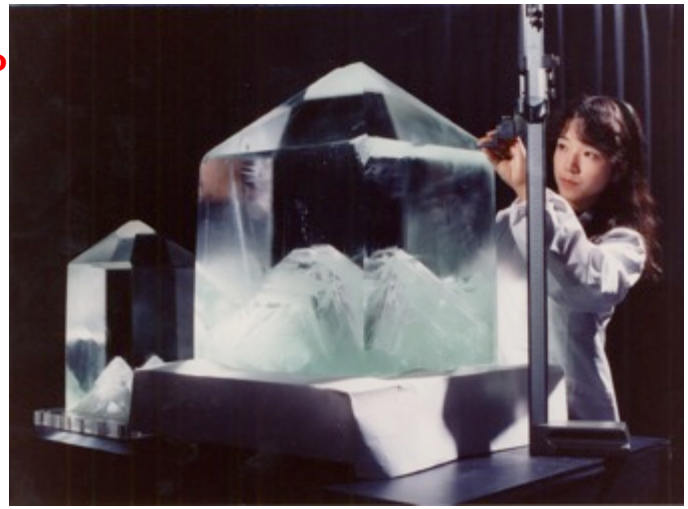
Partially deuterated KDP crystal for broadband OPA











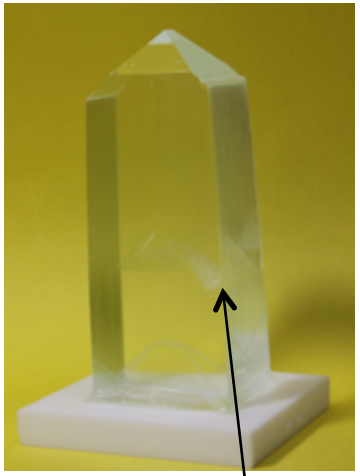
Pumping
- Energy: 8.4 kJ
- Pulse width: 1 ns
- Beam size: 32 cm
- Energy fluence: 10 J/cm^2

OPCPA output
- Energy: ~1.2 kJ
- Pulse width: 0.5 ns

First production of p-DKDP crystal

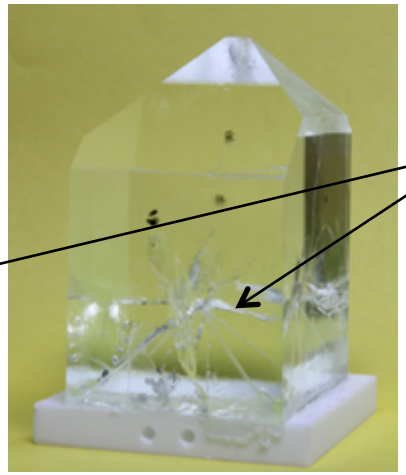
13%

50%



60%

70%

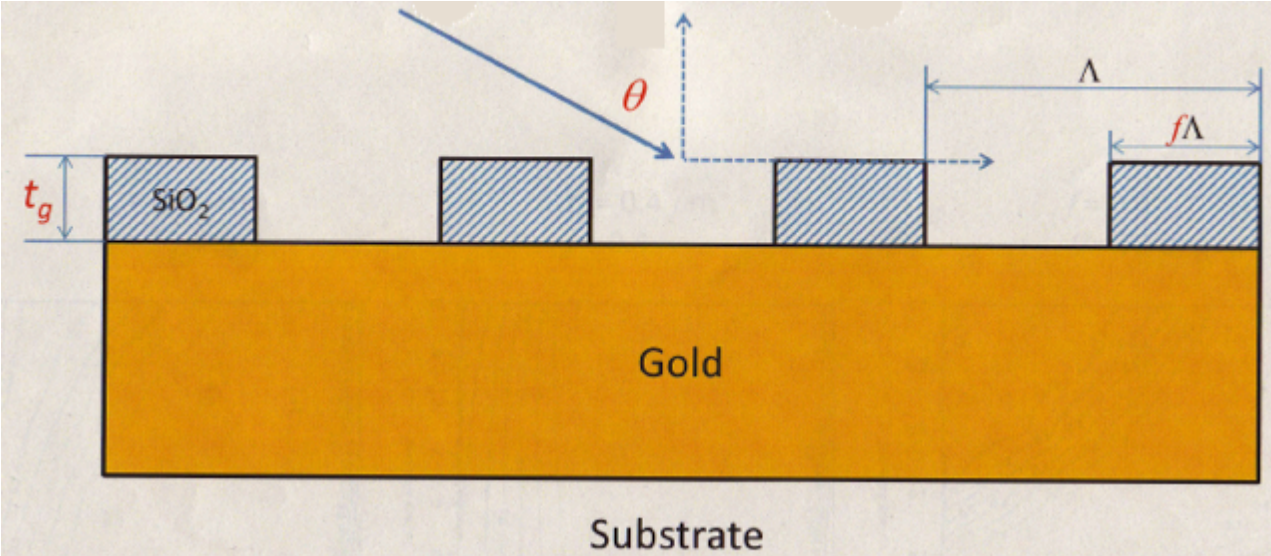


80%

Cracks due to unexpected rotator stopping during the growth process.

Broadband Dielectric Grating

Groove structure



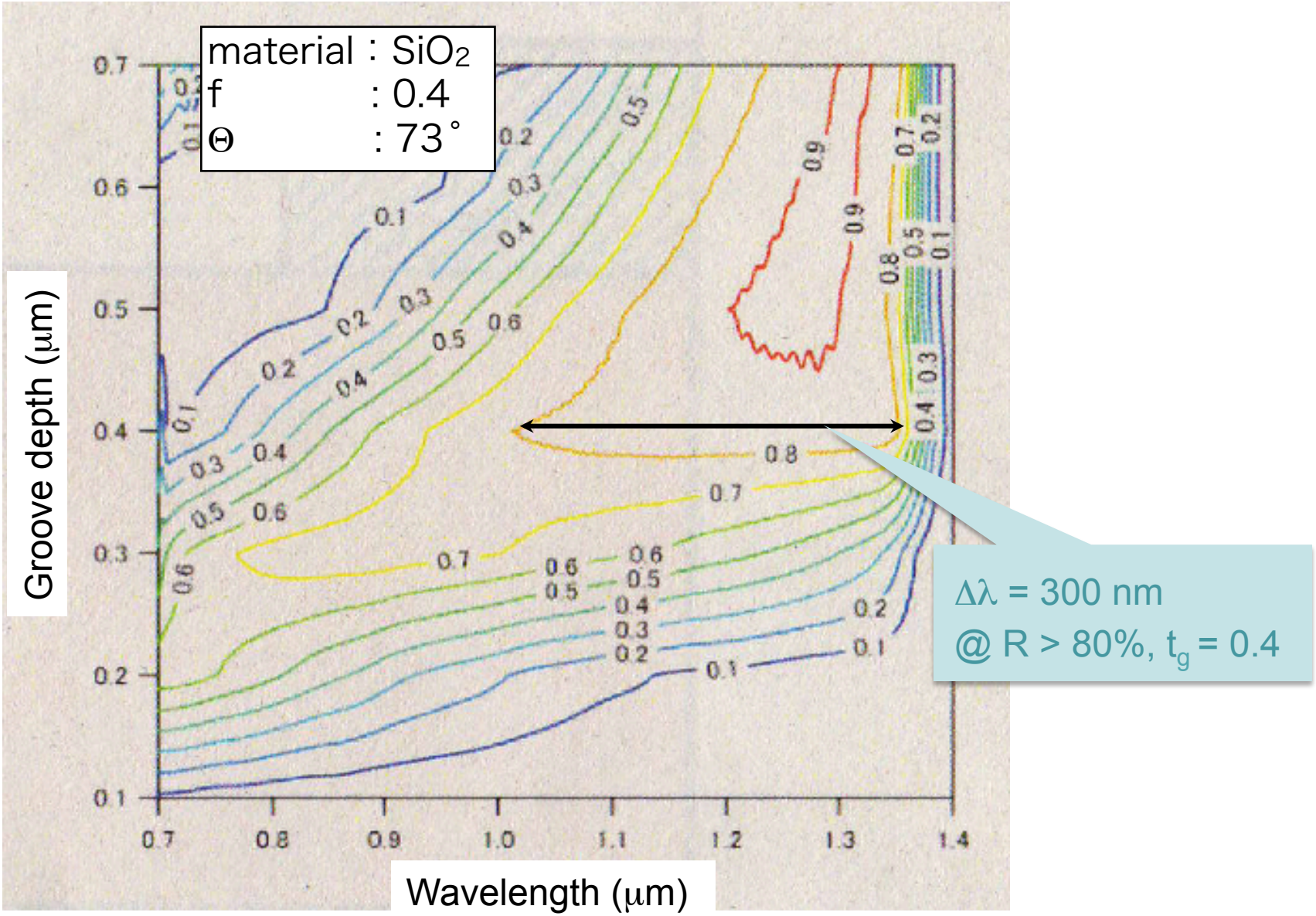
Λ : 0.7 μm (1429 grooves/mm)

f : duty cycle (0.1~0.6)

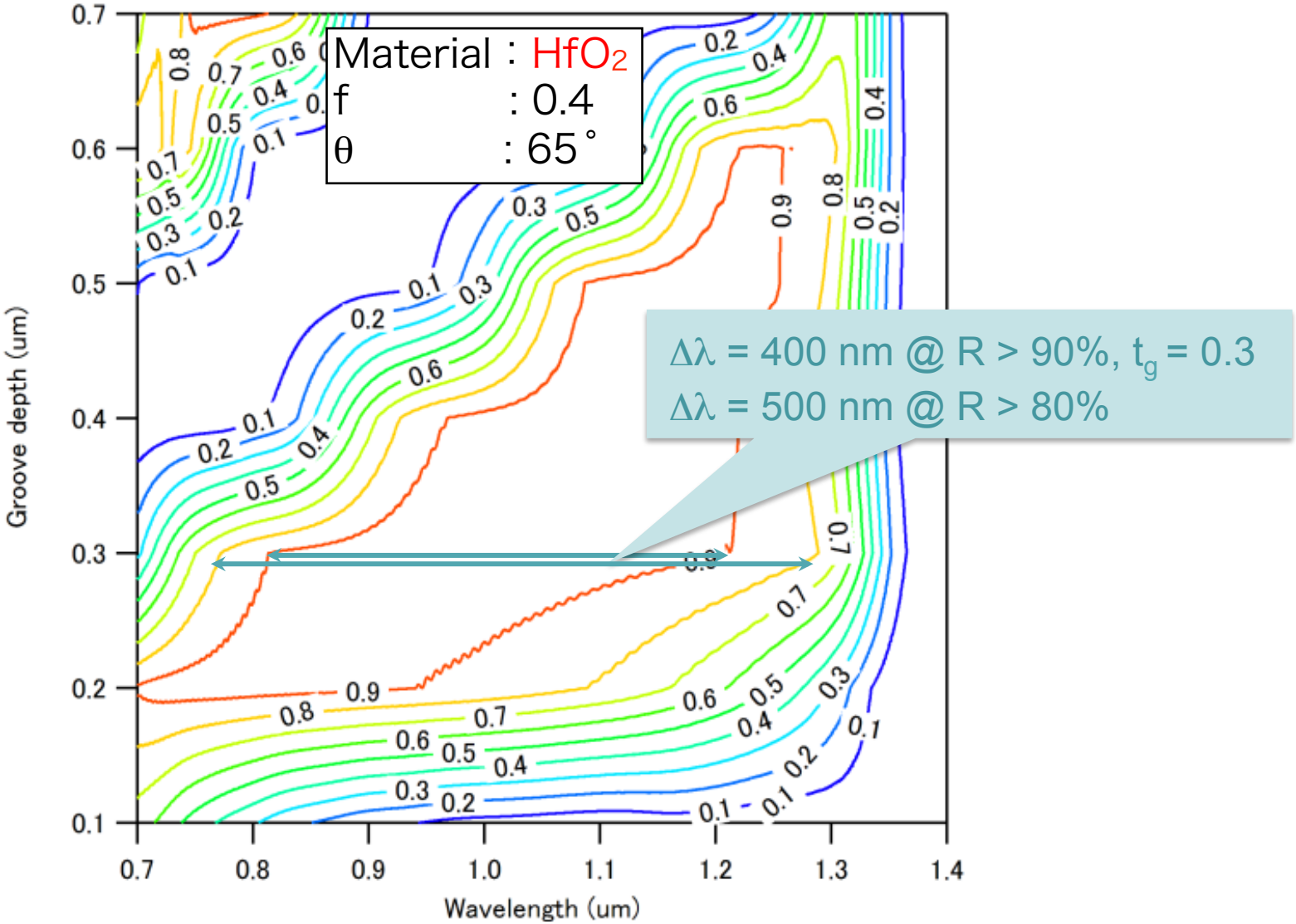
t_g : groove depth (0.1 μm)

θ : incident angle (65-80 degree)

Deflection Efficiency Map with Wavelength and Groove Depth



Deflection Efficiency Map with Wavelength and Groove Depth



Summary

We are starting the challenging basic technology researches for broadband amplification of OPCPA.

1. Arrayed beams pumped OPA for kilo-joule
   - *Random-phased pump OPA shows virtually alignment free for beam combination.*

2. Partially deuterated DKDP
   - Numerical calculation shows
     - *(a) Spectral gain bandwidth is reduced under non-gain-saturation (NGS) in collinear OPA.*
     - *(b) Amplified beam profile looks axicon under NGS in collinear OPA. Also, gain bandwidth is further reduced.*
     - *(c) Non-collinear OPA expands the gain band width.*
     - *(d) p-DKDP expands the gain bandwidth.*
     - *(e) Gain saturation expands the gain bandwidth.*
   - Non-collinear OPA with p-DKDP(40%) under gain-saturation will realize $\Delta\lambda$ = 540 nm, Eff. = 8%.

3. Broadband grating
   - FDTD calculation

     $\Delta\lambda$ = 500 nm @ >80%, HfO_2, t_g=0.3, f=0.4, θ=65°