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High Average Power Frequency Conversion on the Mercury Laser

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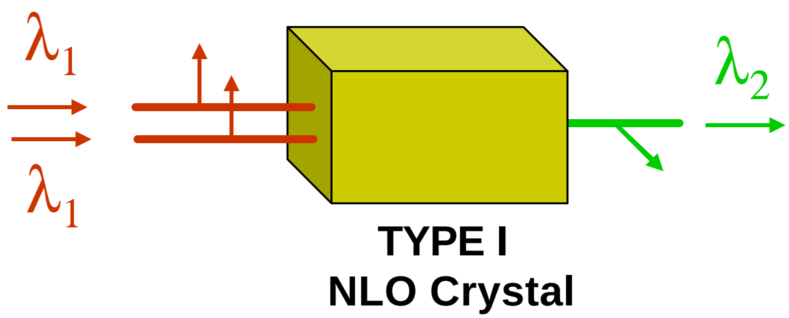
Introduction

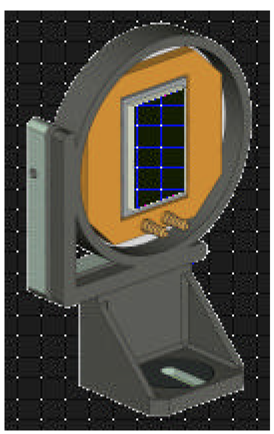
➢ The Mercury laser requires high efficiency frequency conversion at high average power.



	Mercury 1ω Output	Mercury 2ω Output
Wavelength	1047 nm	523.5 nm
Energy	100 J	> 70 J
Pulse Width	3 ns	
Drive	1 GW/cm^2	
PRF	10 Hz	
Avg. Power	1000 W	> 700W

We have investigated sapphire face cooling as well as helium gas cooling for active cooling of the nonlinear optical crystals.

Bulk sapphire cooling



- **Temperature gradients affect the refractive index (thermal dispersion) leading to phase mismatch across the crystal – i.e. reduced conversion efficiency !**
- **Temperature gradients can also lead to internal stress and potential fracture !**

Material Strategy

➢ We have examined the use of four commercially available nonlinear optical crystals with potential for scaling to large apertures

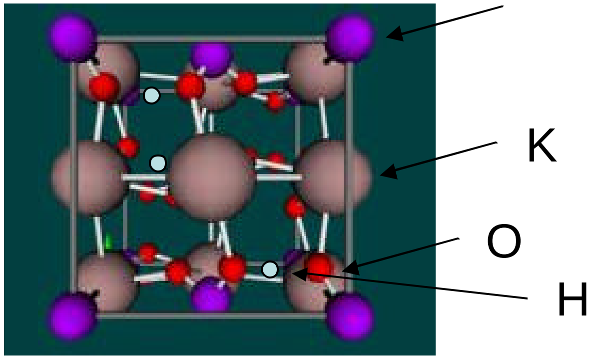
	Type I d_{eff} (pm/V)	Clear Aperture (dia. cm)	Angular Acceptance (mrad-cm)	Wavelength Acceptance (nm-cm)	Absorption at 1 mm (%/cm)	Temperature Acceptance (°C-cm)
KDP	0.26	50+	1.25	19.7	5	11
DKDP	0.23	50+	1.34	5.2	0.1	11
YCOB	1.1	8.5	1.38	1.3	0.1	40
BBO	2.01	2	0.6	2.2	0.1	40

- Large temperature acceptance makes BBO an ideal candidate but large aperture crystal growth is difficult.
- Large aperture high damage threshold DKDP is currently available. Thermal management is incorporated by utilizing multiple plates to obtain high conversion efficiency.
- YCOB offers the best thermal acceptance as well as high relative surface hardness. However, it is a relatively new crystal and requires development to obtain large aperture plates.

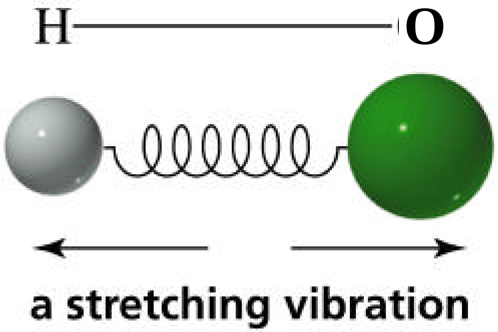
Strategy - A two tiered approach

- **DKDP**: Low risk in acquiring large aperture parts.
- **YCOB**: A moderate risk R&D growth effort with potentially high performance.

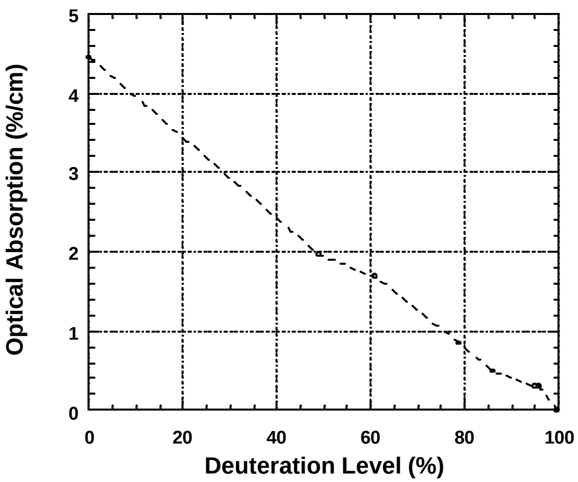
DKDP Material



KH_2PO_4 is a hydrogen bonded water solution grown crystal



- Growth of KDP in heavy water (D_2O) substitutes the heavier deuteron for hydrogen
- Optical absorption is shifted further to the infrared

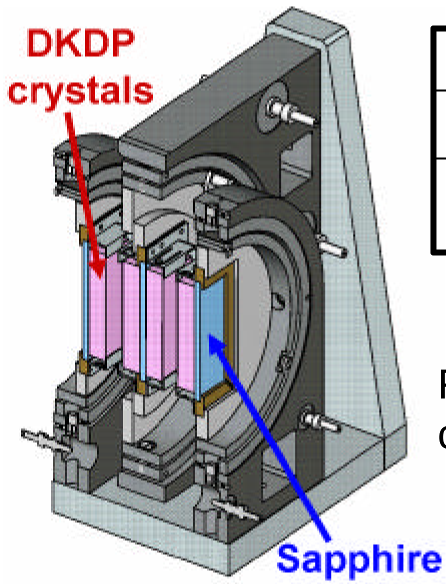


The optical absorption in the near infrared is dramatically reduced with increasing deuteration level

DKDP is harder to grow than KDP but 80% DKDP has been grown to 40 cm apertures

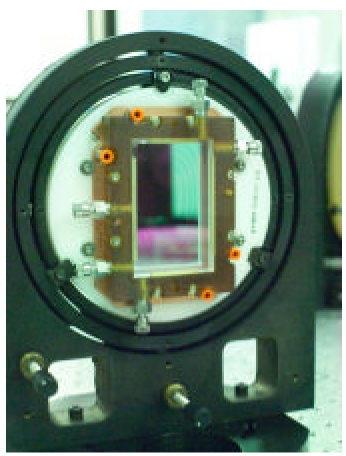
DKDP Frequency Converter

- The lower fracture toughness of the DKDP crystal implies that thinner slabs are required.



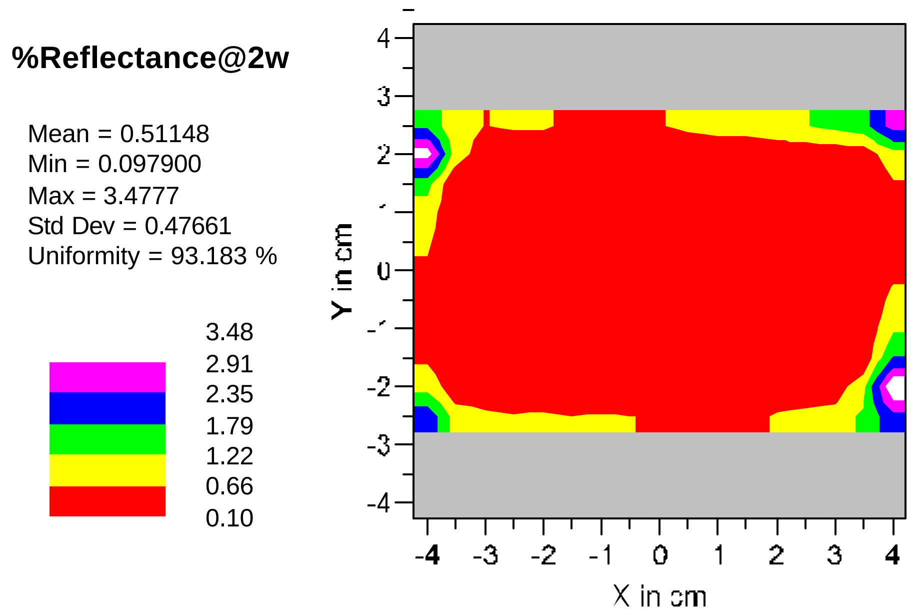
Total Plates	4
Total thickness	45 mm
FWHM Temperature	2 C

Four DKDP plate configuration



Single DKDP test plate configuration

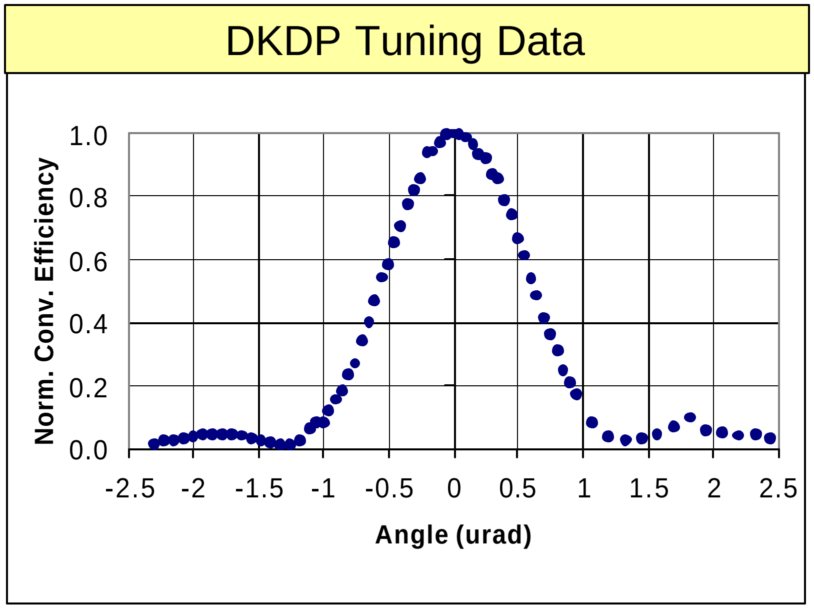
DKDP utilizes sol-gel coatings for antireflection. A dual layer sol-gel AR coating is applied to both surfaces (for both 1047 and 523.5 nm).



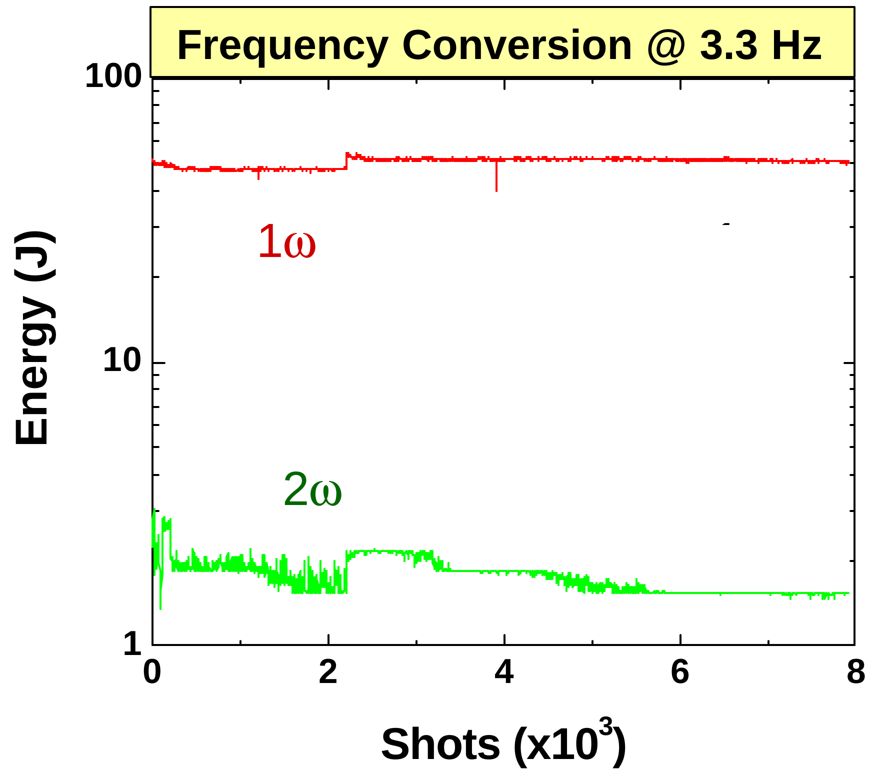
	Slab#1	Slab#2	Slab#3	Slab#4
Mean Reflectivity @ 1ω [%]	0.73	0.69	0.71	0.64
Mean Reflectivity @ 2ω [%]	0.51	0.57	0.52	0.56

DKDP Experiment

➢ We utilized CaF_2 (awaiting sapphire delivery) to test the heat spreader concept. The heat spreader technology was demonstrated with a single plate of DKDP and CaF_2 (a substitute for sapphire) at repetition rate (3.3 Hz).



Internal angular acceptance is measured to be 1.3 mrad-cm (consistent with calculations).

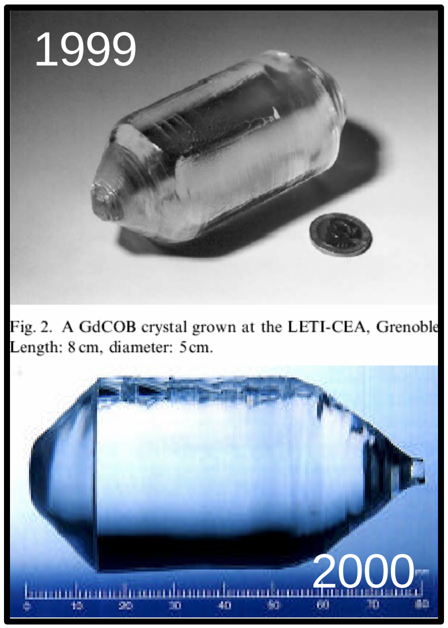


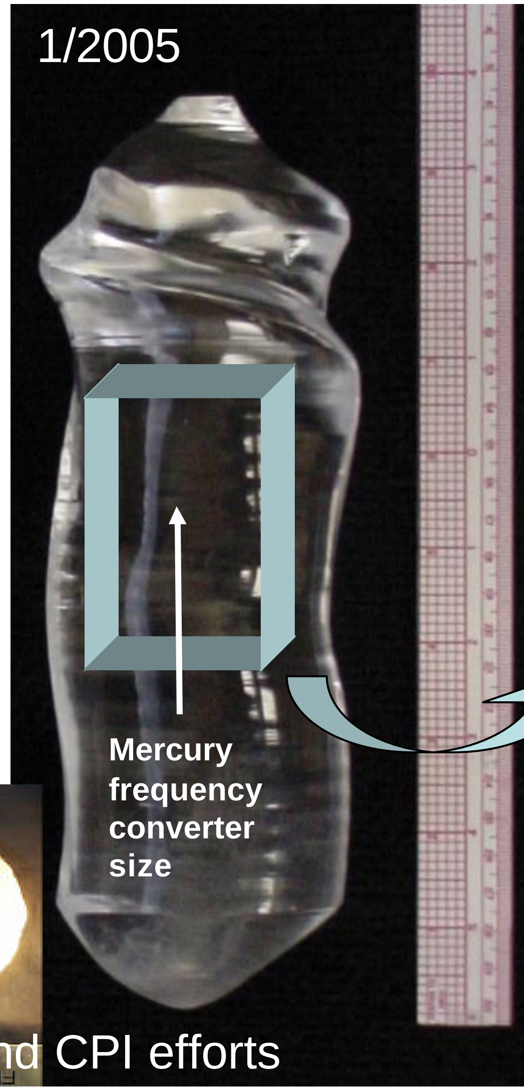
- **No damage to the DKDP-CaF_2 cooler interface was observed up to the 55 J energy level. The 2w power decrease observed in the DKDP during 3.3 Hz operation is consistent with calculations using CaF_2 instead of sapphire.**

YCOB Material

➢ Tremendous progress has been made on growing large size, optical quality YCOB boules.

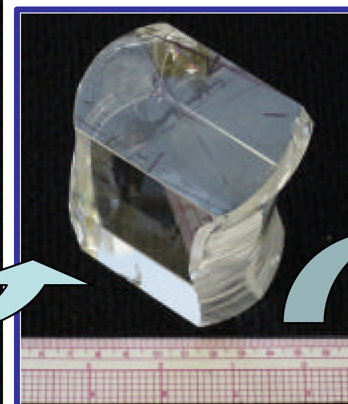
Previous efforts

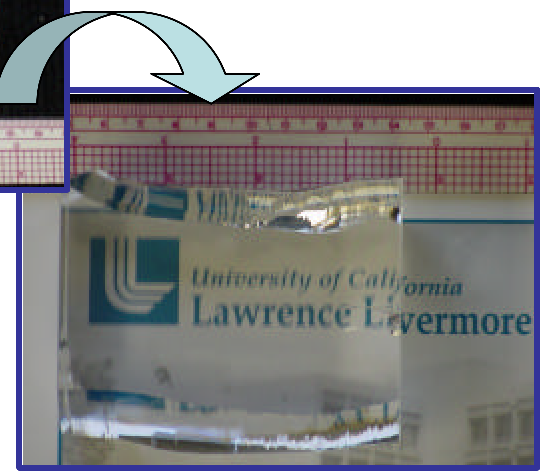




YCOB advantages

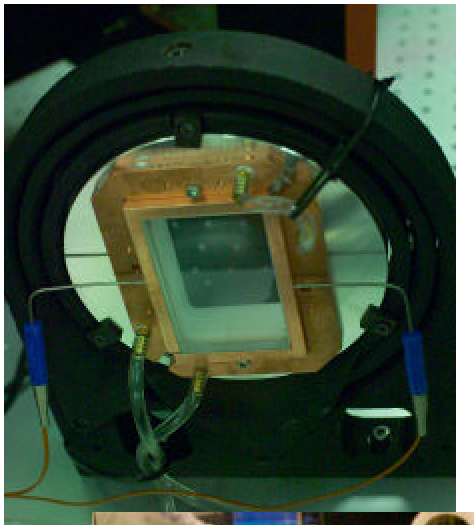
- 3x thermal conductivity of KDP and DKDP
- 3x nonlinear coefficient of DKDP (thinner crystal)
- Equivalent 3ω bandwidth of DKDP
- Thermally insensitive operation at 2ω
- Hardness of quartz – takes hard AR coating



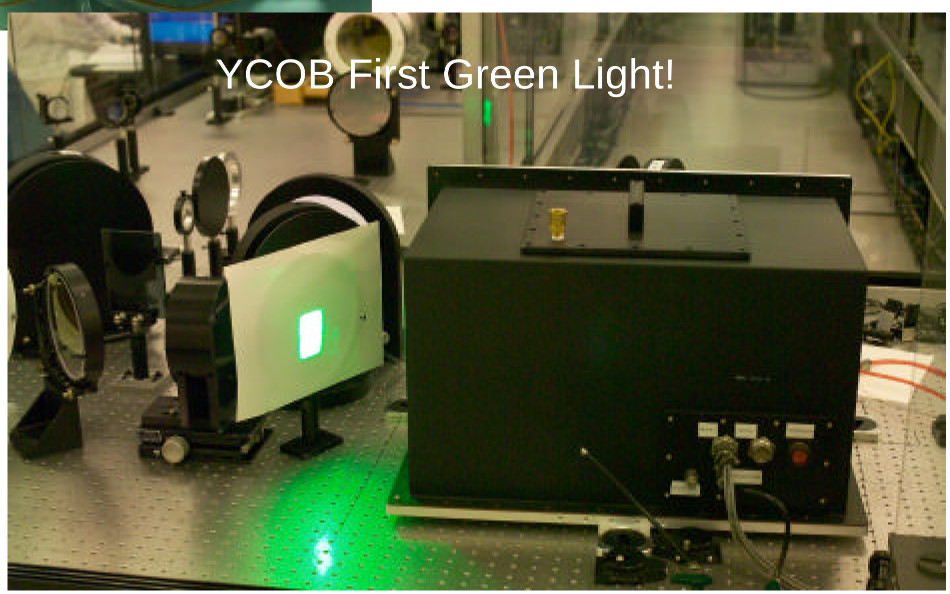


YCOB Frequency Converter

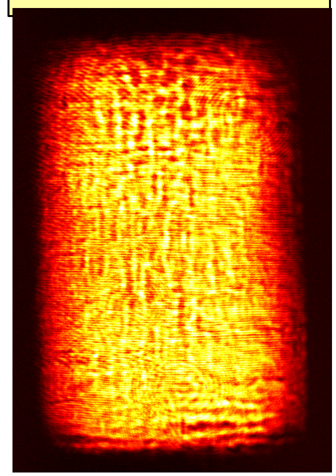
- Full Size YCOB slabs will utilize face-cooling technology with bulk sapphire plates.



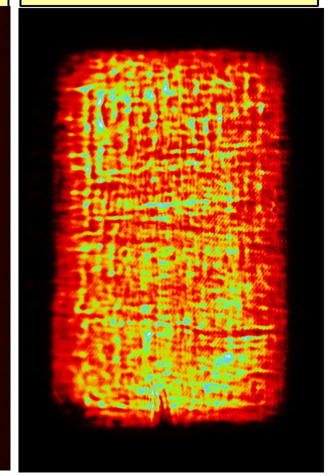
Edge-cooled single plate of YCOB



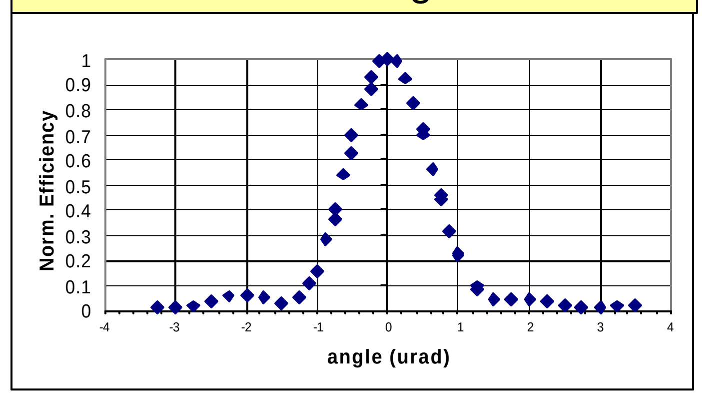
1ω near field



2ω near field



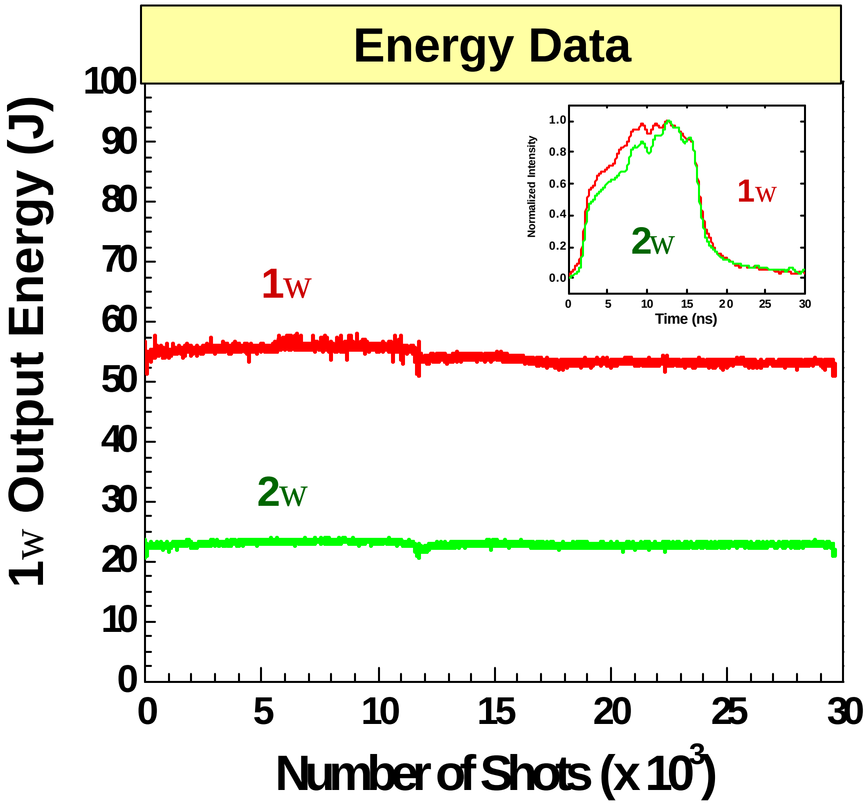
YCOB Tuning Data

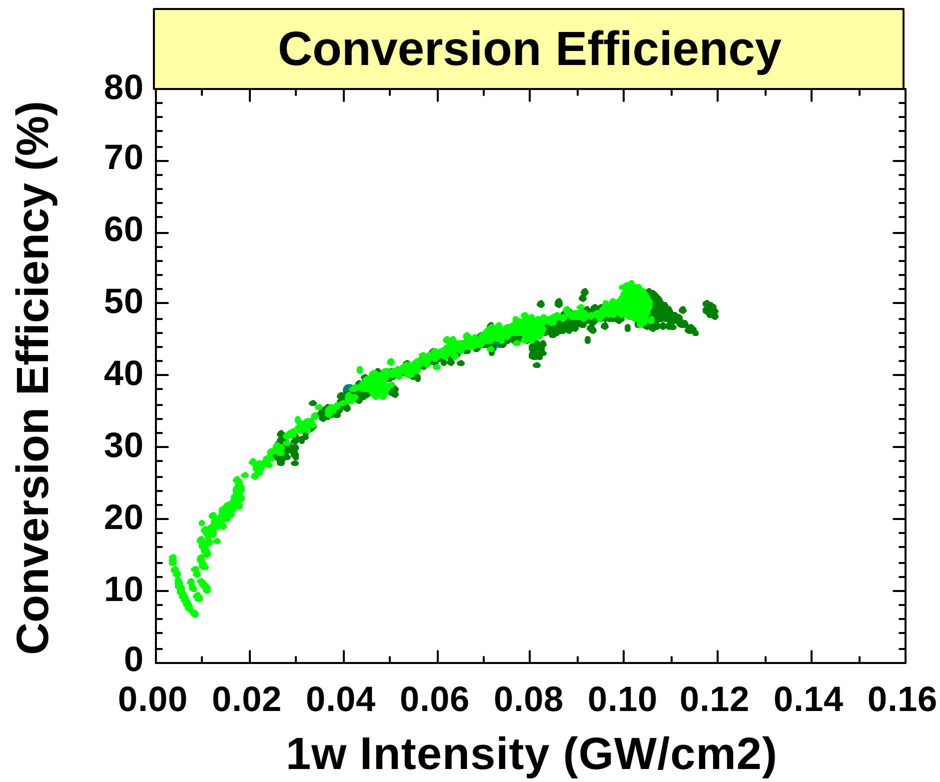


Internal angular acceptance is measured to be 1.2 mrad-cm (consistent with calculations).

YCOB Experiment

- A single plate of edge-cooled YCOB was demonstrated at high average power (0.55 kW input) and high repetition rate (10 Hz).





- **We successfully operated the YCOB frequency converter up to 0.5 kW of 1w drive with 50% conversion efficiency. Higher efficiency is expected at higher drives.**

Summary

- The Mercury laser requires high efficiency frequency conversion at high average power.

- We have implemented a two-tier frequency conversion risk-reduction plan that employs the use of DKDP and YCOB for the frequency conversion crystal.

- We have successfully demonstrated a single plate face cooled DKDP SHG module.

- We have obtained full-size Mercury apertures crystals of YCOB.

- **We have successfully operated a YCOB frequency converter at high average power (15 ns, 10 Hz, 227W @ 523.5 nm) with a conversion efficiency of 50%.**

- **Higher efficiency is expected with shorter pulse widths and improved beam quality.**