Feasibility study on Scalable Self-Phase Locking of two beam combination using stimulated Brillouin scattering phase conjugate mirrors

Hong-Jin Kong, Seong-Ku Lee, and Dong-Won Lee
Dept. of Physics, KAIST,
Daejon 305-701, Korea.
Motivation

• Laser IFE Program has the bottle neck mainly due to the laser driver with high rep. rate over 10 Hz. (NIF operates at 1 shot per several hours)
Why bottleneck?

- For high power and high energy output,
- big size of laser amplifier to reduce the optical damage and gain saturation is necessary.
- But, it gives very high thermal load so that
- it takes too much time to cool down.
How to solve the thermal load?

• Use the pumping source with LD (Mercury, LLNL)
• Use the high thermal conductivity laser materials such as ceramic crystals (K.Ueda)
• Break down the amplifier with small size to reduce the size of the amplifier (H.Kong)
   Beam combination
Beam combination

Break up the amp into small size amp to reduce the thermal load

Phase distortion

Easy to cool down the sliced amps

Each beam has different phases and distorted by the amp’s nonlinearities such as thermal lensing effect and thermal birefringence, different gain profiles and so on.

Piston error

How to combine the beams together in phase? (to fix the piston error)
Phase conjugation mirror (PCM)

Conventional mirror

Phase conjugation mirror
Types of PCM

- 4 wave mixing PCM (complicated, phase controllable)
- Stimulated Brillouin Scattering PCM (SBS PCM) (most simple, random phase piston error)
Stimulated Brillouin Scattering PCM (SBS-PCM)

- Backward scattering – high reflectivity more than 90 %
- Phase conjugate wave – high fidelity
- Scattering by acoustic phonon induced by laser field
- Frequency down shift – negligible; ~1 GHz for liquids
  < 1 GHz for gases
Cross-type PCM amplifier:
Perfect Optical Isolator with PCMs
Proposed by Kong (will be submitted, patent pending)

- Compensate the phase distortions experienced passing through the amplifier by PCM
- Perfect optical isolation
- Insensitive to misalignment: Fixed beam pointing
Beam combination using SBS-PCM for highly repetitive high power and high energy laser
Proposed by H.J.Kong
Optical Review 4, 277-283 (1997)

- Interference between the beams at their boundaries in beam combination gives spatial spiking if their phases are not matched.
- Phase difference between the beams should be less than $\lambda/4$ for constructive interference at the boundary of the combination not give spatial spiking.
Phase locking between beams

- Interference between the beams at their boundaries in beam combination gives *spatial spiking* if their phases are not matched.
- Phase difference between the beams should be less than $\lambda/4$ for constructive interference at the boundary of the combination not to give spatial spiking.
Previous works for phase locking

1. **Overlapping** the SBS focal points locks the phases of the beams.
2. Phase locking by **back seeding** the Stokes shifted beam, which locks the phase of the PC wave.

**a) Overlap of two focal points**

**b) Back-seeding of Stokes wave**
Proposed “Self-Phase locking”

1. Interference between the counter-propagating beams generates a very weak standing wave, which ignites the phonon and locks the phase of the moving grating (phonon).

2. This phonon locks the phase of the SBS wave.

(a) Self-seeding

(b) Backward focusing SBS
Basic concept of a new phase locking
Experimental setup for self-phase locking of two beams

M1&M2, mirror; W1&W2, wedge; L1&L2, cylindrical lens; L3&L4, focusing lens; CM1&CM2, concave mirror; HWP1&HWP2, half wave-plate; P1, polarizer; PBS, polarization beam splitter
Properties of the pumping laser

- Nd³⁺:YAG laser (1064 nm)
- Repetition rate: 10 Hz
- Single longitudinal mode
  Line-width: ~120MHz
- Pulse width: 6-8 ns
- Beam diameter: 8 mm

Beam profile
Properties of SBS medium (FC-75)

- Main component: C$_8$F$_{18}$
- Absorption coefficient: $<10^{-5}\text{(cm}^{-1})$
- Optical breakdown threshold: 100~130GW/cm$^2$
- Brillouin frequency shift: 1.34 GHz
- Hyper sound velocity V: 563 m/sec
- SBS gain coefficient g: 4.5~5 cm/GW
- Brillouin bandwidth: 350 ~ 400 (MHz)
- Hyper sound decay time: 0.8 ns

Reflectivity vs. pump energy
Normal case: No locking

Intensity profile of interference

Intensity profile of interference for 160 shots
**Backward focusing SBS**

228/238 : success (96%)

Intensity profile of interference for 238 shots

Average fluctuation $\mp 0.27 \lambda$

SAE CRP Meeting in Vienna
Concentric seeding beam case #1

178/203 : success (88%)

Average fluctuation $\approx 0.33 \lambda$

Intensity profile of interference for 203 shots
Confocal seeding beam
case #2

Average fluctuation $\approx 0.31 \lambda$

181/199 : success (91%)

Intensity profile of interference for 199 shots
Confocal seeding beam
case #3

178/216 : success (82%)

Intensity profile of interference for 216 shots

Average fluctuation $\pm 0.38 \lambda$
06 Nov, 2003, IAEA CRP Meeting in Vienna

**Average fluctuation** \( \mp 0.09 \lambda 

Two mirrors

256 shots
Average fluctuations for each case

- Normal case
- Backward focusing case
- Self Seeding beam case #1
- Self Seeding beam case #2 (uncoated)
- Self Seeding beam case #3 (AR coated)
Summary

- We have proposed a new scalable phase locking method, “the self-phase locking”.
- For the case of the backward focusing, the average fluctuation of phases between two beams is $\phi 0.27 \lambda \ (96\% \ success)$.
- Further works are necessary to reduce the phase locking fluctuation < $0.25 \ \lambda \ \text{with 100}\% \ success$.
- This new method can easily scaled up to a number of beams to get a high power and high energy laser output for IFE or other applications.
- With or without LD pumped ceramic laser materials developed by K. Ueda, this new technique is expected to advance the Laser Fusion Program, IFE, and also expand the high power laser application area including laser machining.