Use of Optical Phase Conjugation for Laser Irradiation on Laser Fusion Fuel Pellets

Shigeaki Uchida, Oleg Kotiaev, and Takayoshi Norimatsu*

Institute for Laser Technology, Osaka, Japan
*Institute of Laser Engineering, Osaka University, Japan

Second US/Japan Workshop on Target Fabrication, Injection and Tracking

General Atomics, San Diego, California
February 3-4, 2003
Outline

- Why optical phase conjugation technique?
  - Precise and automatic targeting of laser radiation
  - Compensate turbulence inside the fusion reactor
- What is Optical Phase Conjugation?
- Experiments
  - Efficiency
  - Compensation
  - Tracking
- How can it be used to irradiate ICF targets
Wave Front Distortion Compensation
Effect of Optical Phase Conjugation

Phase conjugated waves share identical wave front shape with its original wave while their wave vectors are in opposite direction

→Can be used for automatic compensation / targeting
Phase conjugated wave can restore severe distortion

Initial signal

Distorted signal

Corrected signal

Laser beam divergence = 0.78

Laser beam divergence = 0.71

0.5 mrad
Making Optical Phase Conjugating Waves

- Use diffraction gratings to recode and recover information of optical wave fronts

- **Ways to make gratings** (modulation of refractive index)
  - Brillouin nonlinearity (acoustic waves)
  - Photorefractive effects (electron excitation in semiconductors)

- For high power applications, Brillouin effects are suitable
  - Stimulated Brillouin Scattering (SBS)
  - Degenerate Four Wave Mixing
  - Brillouin Enhanced Four Wave Mixing
Phase Conjugation by SBS

Need certain incident power to overcome SBS threshold
Phase Conjugation by Four Wave Mixing (degenerate)

- Amplification with phase conjugation
- No high intensity focus to the medium
  - (compared to SBS)
Further improvement is possible by Brillouin Enhanced Four Wave Mixing

- The SBS cell provides frequency shift so that the motion of interference and acoustic wave matches resulting in the energy transfer enhancement.
- Helps the two pump beams counter-propagate by themselves.
What is good Phase Conjugation Material?

- **Broad Brillouin resonance**
  - A few hundreds of MHz

- **Low linear & nonlinear absorption**
  - $\alpha < 10^{-5} \text{ cm}^{-1}$, $\alpha_{NL} < 10^{-5} \text{ cm}^{-1} \text{GW}^{-1}$

- **High optical breakdown threshold**
  - $> 100 \text{ GWcm}^{-2}$
Materials for Phase Conjugation

- **Gases**
  - Inert, diatomic, heavy molecular
  - Need to be high pressure

- **Transparent solids**
  - Silica
  - Damage

- **Inorganic liquids**
  - Metal tetrachlorides, Freon-113 (C₂Cl₃F₃)
  - Toxic, carcinogen, ozone layer hazardous
Fluorocarbon liquids for Phase Conjugation

- $F_6C_{16}$ (FC72), $F_8C_{18}$ (FC75)

- Preferred properties
  - Low absorption from UV to IR region
  - High damage threshold
    - $>100 \text{ GW/cm}^2$ at 1µm and 1-ns pulse width

- Chemically stable
  - Environmentally harmless
  - No interaction with optical surfaces
The phase conjugater cell

Liquid: FC72 (C$_6$F$_{16}$)
Experimental setup for BEFWM characteristics

Equipment:

Nd-laser: MOPA
E = 1 J, t = 20 ns, d = 15

SBS cell - Stimulated Brillouin Scattering
BE-DH cell - Brillouin

Enhanced-Hologram cell

Nonlinear medium - liquid fluorocarbon-

BrillouinFC-72 refractive index n = 1.248

sound velocity
vs = 512 m/sec

Brillouin frequency

QWP - Quarter Wave Plate
HWP - Half Wave Plate
T - Telescope, M = 0.4
P - Polarizer

Lasers:

Beam splitter

References

Pin

Video camera

SP - Sensitive

RandomPhase Plate

Optical Delay Line

Signals and energy

S - Signal to be corrected

Probe Beam

Reference Beam

Corrected Signal

20 mJ
Diffraction efficiency strongly depends on probe intensity

BEFWM exhibits 10 times improvement in diffraction efficiency from DFWM

- All intensities are normalized to their optimum intensity
Interaction length of FWM is 30 cm

![Graph showing diffraction efficiency vs. length of BE-DH Cell, cm]
The degree of wavefront distortion recovery

- Laser beam divergence = energy in diffraction limited solid angle / total energy
- Fidelity of PC = 0.71 / 0.78 = 90 %
Experimental Setup for targeting

Target → Laser (Nd: YAG 10pps, ? 100 mJ) → Pol. → BS → Mirror

Aberration → M → P-BS → SF72 cell (Four wave mixing cell)

→ HWP → QWP → SBS cell

→ Image in PC → ODD (M=0.25)
AI plane target

- Diameter: 1 mm
Light from target seen through turbulent media and the compensation effect of phase conjugation

Turbulence compensation and tracking function

Without PC  With PC
How will PC be implemented to ICF target irradiation system
Use of optical phase conjugation technique is proposed for ICF target beaming.

Brillouin Enhanced Four Wave Mixing is a promising technique for the purpose.

Preliminary experiments show the technique exhibits sufficient wavefront compensation and beaming capability.

Improvement for increase energy usage through the system will be one of the future tasks.