High Power Compact Fiber Chirped Pulse Amplifiers at 1558-nm using Er/Yb LMA Fibers and Chirped Volume Bragg Grating Compressors

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Outline

- Introduction
- Chirped Volume Bragg Grating (CVBG) stretchers/compressors
- Compact high power fiber CPA at 1558-nm based on CVBG
  - High power Er/Yb fiber amplifiers
  - CVBG power handling characteristics
  - PM and non-PM CVBG compressor configurations
- Summary
Motivation

- Current Fiber CPA techniques:
  - Diffraction-grating compressors: Large and complex
  - Fiber Bragg grating compressors
  - Hollow-core PCF compressors

- New CVBG pulse compression technology:
  - Compact & robust/simple alignment
  - Potential for both high-power and high pulse energy scaling
Chirped Volume Bragg Grating (CVBG) Stretcher/Compressor

- Rely on Bragg reflection \( \lambda_B = 2n\Lambda(z) \)
  - Same as FBG
- mm-large apertures
  - Main difference from FBG

PTR (Photo-Thermo-Refractive) glass
Chirped Volume Bragg Grating

- Long stretched pulses 0.1 – 1 ns
  (1-cm – 10-cm long CVGB)

- > mJ pulse energies (both extractable and compressible)

- High power/energy handling capacity

- High efficiency (>90 %)

- Compact and robust

- Reciprocal stretching and recompression

- Stretched pulses 80-100ps

- High average power (15W recompressed)
Comparison between Conventional and CVBG Compressors

Diffraction grating

Compressor cavity ~40-cm

Conventional Grating Compressor

Chirped Volume Grating Compressor
PM-Fiber CPA Set-up

18/250 Er/Yb PM DC Fiber Amplifier 10m

Pump diode

XYZ

PM VCBG compressor

PM-Fiber CPA Set-up

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XYZ

PM VCBG compressor

Dispersion compensator

SMF-21

EDFA

CVBG

λ/4

λ/2

λ/4

λ/2

PBS PBS
Amplified 1558-nm signal

![Graph showing the relationship between coupled pump power and amplified signal.](image)
Grating reflectivity is power independent.

1-mm radius beam in the CVBG compressor.
Recompressed Pulse (@ 6-W recompressed power)

- Measured autocorrelation
- BW calculated autocorrelation

Reciprocal stretching/recompression
1.1-ps pulses
Non-PM Fiber CPA Set-up

25/300 Er/Yb DC Fiber Amplifier 20m

SMF-21
SM EDFA
Dispersion compensator

mode-locked fiber laser

Pump diode

Non-PM VCBG compressor

CVBG

λ/4
λ/2

15W recompressed @ 40MHz
2nd Stage Fiber Amplifier

- Er-Yb co-doped
- Core: 25µm, 0.1NA
- Cladding: 300 µm, 0.46NA
- Single transverse mode output:

Fiber made under AFRL LADERA Program
Mode quality
Amplified 1558-nm Signal

- Max Power: 26W
- Rep Rate: 40MHz
- Stretched Pulse Duration: 80-ps
- 1-µm ASE: 15W

Slope efficiency = 40%
Spatial Chirp for Tilted Incidence

\[ d = 2L \sin \theta \]

\[ \Delta \lambda = \frac{2 \sin \theta}{c} \]

c: chirp rate
Spatial Chirp for Tilted Incidence (con’t)

\[ I(y) = I_0 \int_{y-d_{\Delta \lambda}}^{y+d_{\Delta \lambda}} \frac{r^2}{w_0^2} \exp \left( -2 \frac{r^2}{w_0^2} \right) dr = \frac{\sqrt{\pi}}{2} w \cdot \text{erf} \left( \frac{y + d_{\Delta \lambda}}{2w_0} \right) - \frac{\sqrt{\pi}}{2} w \cdot \text{erf} \left( -\frac{y - d_{\Delta \lambda}}{2w_0} \right) \]

1/e² beam-width \( w' \)

Chirp rate: 7.5nm/cm

Incident beam-radius: 1-mm

\( M^2' = \frac{w'}{w_0} \)

Incident angle < 3°

\( M^2' < 1.11 \)
Stretched Pulse: 80-ps
Recompressed Pulse Spectrum

Wavelength (nm)

a.u.
Recompressed Pulse : 1.1-ps

![Graph showing measured autocorrelation for different power levels and calculated autocorrelation.](image)
Self-Phase Modulation Distortion

- SPM induces a phase shift, which is equivalent to the action of a dispersive device with corresponding dispersion order *

\[
\beta^{\text{SPM}}_n = P_0 \gamma Z_{\text{eff}} \left. \frac{d^n (\widetilde{U}_o^2 |\widetilde{U}_{\text{nom}}(\omega)|^2)}{d\omega^n} \right|_{\omega=0}
\]

→ pulse shape distortion
\[\beta_4 \sim 0.2(\text{ps}^4) \rightarrow \Phi_{\text{peak}} = 0.3 = P_0 \gamma Z_{\text{eff}}\]

*Ultrashort-Pulsed Fiber Amplifier in “Ultrafast Lasers: Technology and Applications”, M. E. Fermann, A. Galvanauskas and G. Sucha, eds.,
CVBG Energy Scalability

- Photo-Thermo-Refractive (PTR) glass damage threshold >10-J/cm² for ~1-ns pulses

- Volume grating clear aperture 5mmx5mm
  - 1-J damage threshold for ~1-ns pulses (4mm beam diameter)
  - Multi-mJ damage threshold for sub-picosecond pulses
    - Recently demonstrated 200-µJ 1-ps recompressed pulsed using CVBG at 1064-nm
PM Version of Er/Yb Fiber Amplifier

- Er-Yb co-doped
- Core: 25\(\mu\)m, 0.1NA
- Cladding: 300 \(\mu\)m, 0.46NA
- Single transverse mode output:

_Fiber made under AFRL LADERA Program_
- Polarisation extinction ratio: 13-16dB

Seed: 75-mW 1549-nm signal

5-m long amplifier fiber

35% slope efficiency

1549-nm signal

Power characteristics

amplified signal (W)
coupled pump power (W)
Summary

- 25-um Er/Yb LMA (non-PM and PM versions)
- High power compact fiber CPA using novel CVBG stretchers and compressors
- 15-W average power (recompressed), 1.1-ps pulsed fiber CPA system