Optical Parametric Chirped-Pulse–Amplification Contrast Enhancement by Regenerative Pump Spectral Filtering

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CLEO/QELS 2008
San Jose, CA
4–9 May 2008
Pump spectral filtering in OPCPA systems minimizes the contrast degradation linked to pump intensity noise

• Temporal contrast degradation in OPCPA systems:
  – conversion of pump temporal intensity modulations into signal spectral modulations via the parametric gain
  – high-frequency spectral modulations degrade the contrast of the recompressed signal
  – spectral filtering decreases the pump ASE bandwidth and improves the temporal contrast of the signal

• OPCPA contrast degradation is successfully minimized using a volume Bragg grating in the regenerative amplifier that amplifies the pump pulse
In OPCPA systems, the pump intensity modulates the signal spectrum via the parametric gain

- In OPCPA systems, the input signal is chirped by the stretcher (~linear relation between time and optical frequency).
- The instantaneous parametric gain directly maps the temporal intensity modulations of the pump onto the spectrum of the signal.
- High-frequency spectral-intensity modulations of the amplified signal lead to reduced contrast after recompression.

The parametric gain links the pump ASE spectrum to the signal temporal pedestal.

- Transfer of the pump temporal intensity modulations on the signal spectrum predicted using the OPA transfer function.
- Signal contrast degradation linked to the spectrum and power of the pump ASE.

\[(A): \quad I_{\text{signal}}(t) = I_{\text{signal}}^{(0)}(t) + \alpha(1) [\tilde{I}_{\text{ASE}}(t / \phi) + \tilde{I}_{\text{ASE}}(-t / \phi)]\]

\[(B): \quad I_{\text{signal}}(t) = I_{\text{signal}}^{(0)}(t) + \alpha(2) [\tilde{I}_{\text{ASE}}(t / \phi) + \tilde{I}_{\text{ASE}}(-t / \phi)] \otimes [\tilde{I}_{\text{ASE}}(t / \phi) + \tilde{I}_{\text{ASE}}(-t / \phi)]\]
Filtering the pump ASE and operating the OPCPA at saturation improve the temporal contrast.

- Good agreement between analytical prediction and simulation
- Improvement of the signal temporal contrast
  - operation of the OPCPA at saturation
  - reduction of the pump ASE bandwidth

Saturated OPCPA systems pumped by a narrowband pulse have a significantly improved temporal contrast.
Volume Bragg gratings (VBG) are high-performance narrowband filters

- Longitudinal periodic variation of the optical index written in photothermo-refractive Na-Zn-Al silicate glass doped with silver, cerium, and fluorine using UV light
- Reflectivity at $\lambda_B > 99.5\%$
- Narrow reflected bandwidth $\Delta \lambda (<0.2 \text{ nm})$
- Damage threshold $> 10 \text{ J/cm}^2$ for nanosecond pulses

Regenerative filtering benefits from the large number of passes on the VBG

- A volume Bragg grating (VBG) replaces a cavity mirror in a diode-pumped regenerative amplifier (DPRA).
- Multiple passes (~100) on the VBG significantly decrease the amplification bandwidth.

Regenerative filtering decreases the spectral bandwidth of the amplifier

- Spectral bandwidth of the amplifier evaluated using the optical spectrum of the output ASE in unseeded conditions.
- Reduction of the amplifier bandwidth from 140 pm to 36 pm using an intracavity VBG with a FWHM of 230 pm.

The amplifier bandwidth is reduced by ~4 with regenerative spectral filtering.
Pump spectral filtering was implemented to increase the temporal contrast of an OPCPA system

1. Integrated front-end source
2. Crystal large-aperture ring amplifier
3. Second-harmonic generation

Filtering the pump pulse in the regenerative amplifier decreases the ASE from the high-gain amplification stages

Pump intensity filtering improves the OPCPA temporal contrast in all regimes of operation.

- Temporal contrast improved by preamplifier saturation in the absence of pump spectral filtering.
- Temporal contrast improved with regenerative filtering by ~20 to 30 dB 50 ps before the main pulse.

Regenerative filtering provides effective contrast improvement in all operation regimes.
Pump intensity filtering preserves the signal temporal contrast when significant pump noise is present

- The noise on the OPCPA pump pulse was increased ~100 times by decreasing the power of the integrated front-end source
  - significant contrast degradation without filtering
  - temporal contrast preserved with regenerative filtering

Regenerative filtering significantly relaxes the noise requirement of the OPCPA pump.
Summary/Conclusions

Pump spectral filtering in OPCPA systems minimizes the contrast degradation linked to pump intensity noise.

- Temporal contrast degradation in OPCPA systems:
  - conversion of pump temporal intensity modulations into signal spectral modulations via the parametric gain
  - high-frequency spectral modulations degrade the contrast of the recompressed signal
  - spectral filtering decreases the pump ASE bandwidth and improves the temporal contrast of the signal

- OPCPA contrast degradation is successfully minimized using a volume Bragg grating in the regenerative amplifier that amplifies the pump pulse
Regenerative filtering does not negatively impact the pump pulse generation.

- No beam quality degradation
- No pulse shape degradation (after further amplification and SHG)

Regenerative filtering with an intracavity VBG does not negatively impact the system’s performance.
The short-term temporal contrast is typically measured with a scanning third-order cross-correlator

- Correlation signal measured as a function of the delay between the pulse under test and a frequency-doubled pulse.
- The computer continuously adjusts the input attenuation and detection gain.
- This is fundamentally a multishot acquisition system (~1000 shots).