Spatial characterization of fiber Bragg gratings by Optical Space Domain Reflectometry (OSDR) applying local IR- or UV-light perturbations

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Outline

- Objectives
- spatial information from transmission/reflection spectra
- spatial information from side diffraction measurements
- OSDR concept and implementation
- Comparison
- Conclusions/Prospects
Objectives

grating parameters of interest:
- position along the waveguide
- spatial distribution of index modulation
  i.e. modulation amplitude and period

requirements for measurement principle:
- no grating alteration due to readout
- simple, accurate and fast
for a uniform grating:

\[ \kappa = \frac{\pi \eta \delta n}{\lambda} \]

\[ \kappa L = \tanh^{-1} \left( \sqrt{1 - T_{\text{min}}} \right) \]

\[ \Delta \lambda = \frac{\lambda^2}{\pi n_{\text{eff}} L} \sqrt{(\kappa L)^2 + \pi^2} \]

power spectra do **not** yield
- information about position of the grating
- information about spatial distribution of the index modulation
Phase-sensitive reflectometry

Computation of $\kappa(z)$ from $r(\nu)$

$$r(\nu) = -\int_0^L \kappa(z) \exp(-j2\pi\nu z) \, dz$$

$$-\int_0^L \int_0^{z'} \int_0^{z''} \kappa(z') \cdot \kappa^*(z'') \cdot r(z'', \nu) \cdot \exp[j2\pi\nu(z'' - z')] \, dz' \, dz''$$

simple for weak gratings:
inverse Fourier transform

cumbersome in general:
inverse scattering
Side diffraction method I

yields information about position
yields information about spatial distribution of amplitude
no information about spatial distribution of period
Side diffraction method II

![Graph showing index modulation vs. position in mm]

- Y-axis: Index modulation (x \times 10^{-3})
- X-axis: Position in mm

Graph showing a decrease in index modulation with increasing position in mm.
**OSDR concept I**

Weak grating approximation:

\[ r(\nu) = -\int_{0}^{L} \kappa(z) \exp(-j2\pi\nu z) \, dz \]

Also valid for strong gratings, if

\[ |\lambda - \lambda_B| > \Delta\lambda \]
\[ |\nu| = |\nu_{\text{meas}}| > \Delta\nu \]

\[ \nu = \frac{kn_{\text{eff}}}{\pi} - \frac{1}{\Lambda} = 2n_{\text{eff}} \cdot \left[ \frac{1}{\lambda} - \frac{1}{\bar{\lambda}_B} \right] \]
modified coupling coefficient:  
\[ \tilde{\kappa}(z) = \begin{cases} 
\kappa(z) & \text{for } z \leq z_S \\
\kappa(z) \cdot \exp(j\delta\phi_S) & \text{for } z \geq z_S 
\end{cases} \]
$$\frac{\partial P_D}{\partial z_S} = \frac{\partial R(z_S; \nu_{\text{meas}})}{\partial z_S} = 2 |r(\nu_{\text{meas}})| \cdot \delta \phi_S \cdot |\kappa(z_S)| \cdot \sin \left[ 2\pi \nu_{\text{meas}} z_S + \varphi_{\kappa}(z_S) - \varphi_0 \nu \right]$$

$$\kappa(z) = |\kappa(z)| e^{j\varphi_{\kappa}(z)}$$
New heating laser sources

drawback of previous experiments using a He-Ne laser:

- fiber wasn't absorbing at heating wavelength
- grating had to be coated with an absorbing layer
- problem with limited coating homogeneity

present approach using:

**CO laser**
\[ \lambda = 5\mu\text{m} \]
local phase shift due to heating

**UV laser**
\[ \lambda = 244\text{nm} \]
local phase shift due to heating and transient index change
envelope yields grating strength
phase yields grating period
reconstructed absolute value distribution of $\kappa$ from OSDR signal
reconstructed phase distribution of $\kappa$ from OSDR signal
Comparision I

\[ \kappa \text{ in } 1/\text{mm} \]

- Red: HeNe side diffraction
- Blue: UV OSDR
- Green: IR OSDR

Position in mm
Comparision III

- Measured power spectrum
- Calculated from $\kappa$ distribution without phase information
- Calculated from $\kappa$ distribution with phase information
Conclusions

OSDR yields complete $\kappa(z)$-characterization

direct and local readout of $\kappa(z)$ from measurement
no inverse scattering evaluation required

easily detectable signals
by using periodic disturbances and phase sensitive detection

UV and IR laser are suitable probe lasers for OSDR

good coincidence between OSDR and side diffraction results

Prospects: better spatial resolution
measurement during grating inscription
measurement of long period gratings