論文の内容の要旨

Abstract of Dissertation

Characterization of Stimulated Brillouin Scattering in Optical Fibers
—Study on Discrimination of Strain and Temperature in Fiber Optic Nerve Systems—

（光ファイバ中の誘導ブリルアン散乱の特性評価
—光ファイバ神経網における歪と温度の分離測定の検討—）

ゾウ　ウェイウェン
鄒　衛文

Owing to the advantageous correlation-domain continuous-wave-based technique, fiber optic nerve system of either Brillouin optical correlation-domain analysis (BOCDA) or reflectometry (BOCDR), rather than Brillouin optical time-domain analysis (BOTDA) and reflectometry BOTDR, has been theoretically investigated and experimentally realized to provide outstanding performances in diagnosis of fully-distributed strain or temperature disturbances with an extremely-high spatial resolution of from tens of centimeters to several millimeters along the whole fiber under test (FUT). Regardless the ability of how short segment can be diagnosed, either BOCDA/R or BOTDA/R via measurement of a single parameter (i.e., Brillouin frequency shift, BFS) is unable to distinguish the response to strain from the response to temperature.

The target of this dissertation is to study discriminative measurement and simultaneous sensing of strain and temperature in fiber optic nerve systems.

First of all, we have focused on investigating and clarifying the feasibility/possibility of discriminative sensing by utilizing different acoustic resonance peaks in a newly-proposed fiber structure, a w-shaped triple-layer optical fiber with high-delta core and F-doped inner cladding (F-HDF). For this purpose, we proposed a modal analysis based on two-dimensional (2-D) finite element method for evaluating the Brillouin gain spectra (BGS) in optical fibers with 2-D complicated geometry and/or 2-D arbitrary refractive-index profile. Our analyzed examples, a standard single-mode optical fiber (SMF) and a PANDA-type polarization-maintaining fiber (PANDA-PMF) drawn from the same design of the optical core, are in good agreement with the experimental results. The experimental arrangements for both SMF and PANDA-PMF were respectively modified from the traditional pump-probe scheme by taking use of a single-sideband modulator (SSBM), high-bit A/D data acquisition and rather-high probe power to improve the measurement accuracy within 0.05 MH~0.10 MHz. The merits of our proposed modal analysis and the improved experimental arrangement of BGS characterization has been manifested and validated by investigating optical fibers drawn from the same preform but under different tensions.

To study w-shaped triple-layer F-HDF optical fibers, a preliminary measurement and a systematic acoustic modal analysis were both undertaken. We found experimentally that multiple acoustic resonance peaks with wide neighboring frequency spacing have different dependences on strain and temperature, especially between the fundamental L_{01} mode and the highest L_{04} mode since they feel the largest difference of germanium dopants from fluorine dopants. This material difference is estimated to be useful to enhance discriminative performances because the fundamental L_{01} mode and the L_{03} mode can be separated into germanium core and the F-doped inner-cladding region while with comparable gain (~-5 dB) by using proper fiber designing.

Strain and temperature dependences of Brillouin resonance frequencies in GeO_2-doped optical fibers and F-doped optical fibers have been respectively investigated to clarify the physical nature of the silica materials lying behind the discriminative measurement. Our results show that either strain dependence or temperature dependence is significantly originated from the nonlinearity of Young's modulus of silica materials, and that germanium dopants decrease the nonlinearity of Young's modulus while fluorine doponts increase the nonlinearity. Furthermore, we found that the fabrication conditions, such as draw tension, can increase the difference of strain and temperature dependences, which provides a more degree of freedom for fiber designing to enhance the discriminative measurement.

On the other hands, when analyzed the BGS in PANDA-PMF, it was proved that, in the process of stimulated Brillouin scattering in PANDA-PMF, the acoustic wave generated by the counter-propagating pump-probe light waves along each principal polarization has the same displacement distribution along the fiber's cross section. This fact indicates that the acoustic wave generated and intensified by *x*-polarized light waves can be used as an acoustic grating to diffract a *y*-polarized light wave if it has a birefringence-determined wavelength/frequency deviation from the *x*-polarized pump light. We have experimentally characterize the frequency deviation with a precision as high as ~4 MHz, which corresponds to a birefringence accuracy of $3*10^{-8}$.

Strain and temperature disturbances influence linearly the birefringence but in a far different behavior from their influences to the BFS. For example, strain increases while temperature decreases the birefringence. We proposed to utilize the characteristics as a novel technique to discriminate the response to strain from that to temperature by use of the PANDA-PMF. Our experimental results show that simultaneous measurements of the BFS and the birefringence-induced frequency deviation can provide an extremely-high reproducible accuracy of 3~4 $\mu\varepsilon$ and 0.02~0.03 ^{o}C.