

論文内容の要旨

Optical fiber sensors can be used in harsh measurement situations where conventional sensors are not well suitable to use because of the important advantages of optical fiber sensors, such as electromagnetic interference immunity, lightweight, compact, high flexibility, and multiplexing capability. Especially, in the applications where optical fiber sensors offer new capabilities, e.g., distributed sensing, Fiber Bragg gratings (FBGs), optical fiber sensors possess a distinct edge over other types of sensors. Besides, the use of plastic optical fibers in optical sensors is undergoing rapid growth. Sensor heads can be made on plastic optical fibers, and some optical components, such as FBGs, can be produced in plastic optical fibers, creating new opportunities for optical sensor applications.

In an optical fiber sensor, the physical parameters of working optical waves, e.g., time, wavelength, power, phase and polarization, are modulated by the variation of ambient circumstance, e.g., temperature, pressure, displacement, etc., around the optical fiber. By analyzing the modulated optical parameter, we can estimate the variation of corresponding measurands. Typical optical sensor types include Fiber Grating sensors, fiber-optic gyroscopes (FOGs) which is considered as the most cost-efficient solution for various inertial navigation applications, fiber-optic current sensors, Optical Time Domain Reflectometer (OTDR) which is one of the most well-developed and commercialized in-line fiber sensors or diagnostic tools, optical fiber acoustic sensors or optical fiber hydrophone systems, etc. Fiber-optic chemical sensors or biosensors aiming at the measurement of certain type of gas are growing fast as well.

With the industry requirements of wide-region/remote sensing development, optical fiber sensors can be classified as point sensors, distributed sensing and quasi-distributed sensing. Point sensors measure a particular measurand at a particular location, examples include chemically sensitive dip-in probes for species monitoring, and resonant structures mounted at the end of the fiber for pressure or acceleration measurement. Distributed sensors discriminate in the spatial mode, and in

this way, the measurand can be determined along the length of the fiber itself. This principle has been employed widely in the measurement of temperature using non-linear effects in fibers, such as Brillouin or Raman scattering or in some types of strain sensing. A style of sensor that is somewhat “in between” these two types of sensors is termed quasi-distributed sensing, where the measurand information is obtained at particular and pre-determined points along the length of a fiber network, e.g., using FBGs.

In this dissertation, I aim to develop a quasi-distributed optical fiber sensing system that is capable of tele-monitoring the change of temperature, pressure and the occurrence of gas leakage along pipelines. Firstly, I measure the time variation caused by the fiber expansion to measure the fiber tensile strain force. In addition, I detect the intensity of gas spectroscopy to detect the occurrence of gas leakage along gas pipeline. In the end, I detect the intensity of the Fresnel sensing signal varied by transmission media to assess the transmission media.

In Chapter 2, I study on a long term instability of our quasi-distributed optical fiber sensing technique, polarization fluctuation induced by the twisting of a fiber or the birefringence of fiber links. I introduce a more practical method to overcome the polarization fluctuation by polarization scrambled pulse train (PSP), in which the polarization state of each pulse is randomized. The PSP stability is analyzed and demonstrated on a multi-region fiber strain measurement using pulse correlation technique under various polarization states.

The variation of measurands, e.g. temperature, pressure, strain, etc., would cause the expansion/compression of sensing fibers which lead to the increase/decrease of the path length of optical signals that finally vary the transmission time of sensing signals. The transmission time deviation containing abundant information of ambient environmental change, is a valuable parameter in optical fiber sensors. However, it is difficult to be detected by traditional electrical components as the time drift normally occurs in picosecond. One of the most effective ways to realize high precision timing control/measurement is to use pulse correlation measurement. In our lab, optical pulse correlation sensing technique [1-4] has previously been proposed, which has an advantage of high accuracy and good response linearity. By applying region selectable technique [5-7] to this pulse correlation sensing technique, a quasi-distributed optical

fiber sensing has been successfully constructed. Unfortunately, some long-term instabilities, time drift fluctuation and polarization fluctuation have degraded system stability during long transmission line [8]. Consequently, the technique should be improved to be independent of transmission line.

Correlation techniques using second harmonic generation (SHG) in a suitable optical crystal are the most popular and cost-effective experimental methods. The resulting second-harmonic wave is detected by a conventional, slow optical receiver that is capable of sub-picosecond-order time resolution in temporal waveform measurement, such as a semiconductor photodiode or an Avalanche photodiode. However, when using SHG for pulse correlation measurement, the problem is that the SHG conversion efficiency is strongly dependent on the polarization state of the incident light wave. Thus, if the incident polarization state is affected, e.g., by birefringence in the transmission line or optical fiber twisting, the output signal of the pulse correlation measurement is easily disturbed.

The principle as well as the implementation of the stabilization of pulse correlation measurement by polarization scrambled pulse train (PSP) is going to be explained in detail. The correlation signal detected by SHG, including a pulse correlation term and a pulse independent term, in a collinear geometry is calculated. Mathematical analysis of the polarization-induced fluctuation of pulse correlation term is conducted which is followed by a stabilization concept using pulse scrambled pulse train (PSP). A GS-LD modulated by an external RF signal works as a low-coherence pulsed light source, with the central wavelength of 1550nm, frequency of 1.5GHz. By splitting the incident signal into two beams and precisely adjust the polarization state and pulse transmission time of each beam, a PSP was successfully generated. Experiments about the polarization stabilization of pulse correlation measurement using PSP has been demonstrated by a PSP/PMP, an optical coupler, a half wave plate (HWP), a quarter wave plate (QWP), and a pair of SHG and APD. Afterwards, wide region optical pulse correlation sensing is explained, including the principle of correlation sensing, the impact of polarization instability on tele-monitoring and improvements of optical pulse correlation technique using PSP light source. Experimental demonstration has been conducted on a pulse correlation sensing utilizing a PSP light source. In the experiment of sensitivity stabilization against polarization instability, the SHG output signal with PSP light

source has been suppressed within 4.5%, comparing with 89.5% using PMP as light source. The PSP based optical pulse correlation sensing was stabilized at around 0.55 mV/ps at any polarization condition. Strain measurements along a meter-long region over kilometer distances in varying polarization states have been successfully performed, resulting fluctuation in the output signal was less than 1%.

In Chapter 3, I study gas spectroscopy sensing and apply it to the quasi-distributed gas pipeline monitoring system to realize tele-monitoring of gas leakage in different sensing regions.

Pipelines are playing an increasingly important role in energy transportation, especially in the process of shipping hydrocarbons over long distances. However, being laid over long distances in remote areas, pipelines are typically affected by geohazards and harsh environmental conditions that may cause failures. Pipeline failure can lead to large business losses and environmental damage. Consequently, there is growing demand for the maintenance of pipeline over long distances. A system is required that has the ability to detect and locate problems such as leakage and emission along the pipeline. A technique that can perform multipoint and real-time monitoring is expected.

A lot of electrical gas sensing systems have been explored in order to satisfy the requirements of the gas industry. Gas sensing electrodes are free of the liquid junction potential problems associated with pH and ion sensitive electrodes, and are free of redox interferences, but the technique suffers from the limitation of dissolved gas. A homogeneous semiconductor gas sensor array simply detects the resistivity from a variety of gases. The sensors can convert the concentrations of gases into an electrical signal. However, these electrical gas sensors are basically onsite point sensors with power supply.

Gas absorption spectroscopy offers direct, accurate and highly selective means of gas measurement. Optical gas sensors can realize high sensitive detection of gas concentration. However, they are not applicable in a long distance monitoring system, since they are usually composed of separate optical components. Optical fiber sensors are proven to be an effective method for environmental monitoring in various environmental processes. When we apply optical fiber sensing technique to gas

spectroscopy, we can probably realize a long distance optical gas tele-monitoring technique.

In this chapter, I explain a new concept, which is capable of addressing multiple gas sensors in one single fiber, by inserting optical gas sensors into our region selectable system. Wavelength scanning LD and wavelength analyzer connect with optical fibers and region selectable reflectors to insert the light source and receive the results of spectroscopy of multi- regions.

To distinguish multi-regions, gas spectroscopy combines with a region selectable technique by synchronizing a fiber bragg grating (FBG) reflector with the target absorption line in each sensing region. Spectroscopy performance under different temperatures, pressures and different leakage occurrences is measured. The possible optical loss is going to be discussed and the available sensing length of the system will be estimated.

Multi-region tele-monitoring experiment was demonstrated. Available numbers and coverage of multi-sensing regions were estimated using fiber propagation loss and the loss of sensing unit. Also, I studied the impact of absorption line broadening under varied temperatures and pressures.

The chapter initiates with the concept of region selectable gas sensing by tele-spectroscopy where the concept of quasi-distributed region selectable gas sensing is explained for one of its applications, long distance pipeline maintenance. The basic tele-spectroscopy technique and its performance are going to be discussed. Impact factors such as absorption line broadening and FBG instability have been estimated. Afterwards, I explain multi-region gas sensing. The multi-sensing situation is discussed. On top of that, the performance of multi-region gas sensing over a km long distance is demonstrated and discussed. Finally, the summary of this study is given.

In Chapter 4, I will construct a quasi-distributed remote sensing using graded index plastic optical fiber (GI-POF) [9] sensor with OTDR measurement. By detecting the Fresnel Reflection, the reflective index of the transmission media can be assessed which enables the estimation of the transmission media. Three-region sensing performance has been demonstrated using OTDR, GI-POF, and single mode fiber. The sensing length

and maximum number of sensing regions are estimated. The technique has potential to be used for gas sensing.

A conclusion and discussion is presented in Chapter 5. The demonstration performance of the whole study is going to be summarized. A future research plan is presented.

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