



OZ Optics

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Fiber Optic Distributed Strain and Temperature Sensors (DSTS)

BOTDA Module

For more information about our strain and temperature sensor system and related products, please visit www.ozoptics.com

Features

- Uses standard telecom single mode fibers for strain and / or temperature measurement
- Real-time measurement of strain and temperature
- High spatial resolution, strain, and temperature resolution and accuracy
- DLL available for system integrator

Performance at a glance

- As low as 0.1 m spatial resolution
- Max. 100 km sensing range with max. 160 km fiber length

Product Description

OZ Optics' Foresight™ series of fiber optic Distributed Strain and Temperature Sensors (DSTS) BOTDA modules are sophisticated sensor systems using stimulated Brillouin scattering in optical fibers to measure changes in both strain and temperature along the length of an optical fiber. By deploying a sensing cable that includes standard telecom single mode fiber, users can detect when and where the strain or the temperature of the object has changed and correct potential problems before failure occurs.

A unique feature of our Foresight™ DSTS system is its ability to measure temperature and strain, simultaneously and independently, allowing regions of temperature induced strain to be identified.

Oil and Gas applications



Oil and Gas Pipeline Monitoring

- Pipeline leakage monitoring
- Up to 100 km sensing range per channel
- High spatial resolution supports localized measurement with long sensing range
- Short acquisition / response time



Oil and Gas Well Monitoring

- Well integrity management
- Temperature, strain and pressure monitoring with proper sensing cable and installation
- Not sensitive to hydrogen which may change the attenuation of the fiber



Refinery Efficiency Sensing

- Improve the efficiency of the refinery per distributed temperature profile
- Reduce downtime while ensuring safety levels
- Uses low cost telecom single mode fiber cable

Civil Engineering applications



Dam Monitoring

- Dam internal temperature monitoring
- Crack / sediment / deformation / seepage monitoring
- Up to 100 km sensing range per channel



Structural Health Monitoring (SHM)

- Sediment monitoring
- Strain and crack monitoring
- Up to 100 km sensing range per channel
- High spatial resolution supports localized measurement with long range object

Civil Engineering applications *continued*



Geohazard Monitoring

- Landslide, subsidence and deformation of levee / ground / highway monitoring
- Can monitor trends in ground movement
- Up to 100 km sensing range per channel



Highway Safety Monitoring

- Internal temperature / strain monitoring with proper sensing cable and installation
- Highway subsidence monitoring
- Up to 100 km sensing range per channel

Utility and cable applications



Overhead Power Line Monitoring

- Lightning strikes, icing and broken wires can be detected
- Up to 100 km sensing range per channel
- No additional components required along power line route
- Easy deployment



Submarine Cable Monitoring

- Ongoing quality / status monitoring throughout the life of the cable
- May only require one fiber
- No additional components required along the route



Quality Inspection of Fiber Optic Cable

- More sensitive to strain than OTDR
- High level quality control based on high level technology
- Can monitor the quality of power cable / OPGW with optical fiber unit

Security, Cryostat, and Fire applications



Border Security Monitoring

- Fast, dynamic measurement
- High precision of event location
- Can work in conjunction with a video surveillance system



Cryostat Temperature Sensing

- Able to measure temperatures as low as 25 K
- May use low cost telecom single mode fiber
- Up to 100 km sensing range per channel
- High spatial resolution with good temperature resolution / precision



Building Fire Detection

- Fast, dynamic, and accurate temperature measurement
- Up to 100 km sensing range per channel
- May use low cost telecom single mode fiber cable

Specifications

Parameter		Description		
Spatial Resolution		1 m to 50 m	0.5 m to 50 m	0.1 m to 50 m
Dynamic Range		30 dB	30 dB	25 dB
Number of Channels		2 to 25 ¹		
Sensor Configuration		Fiber Loop, BOTDA+BOTDR combo unit is optional		
Maximum Fiber Length		160 km		
Sensing Range		100 km		
Spatial Accuracy		as low as 5 cm		
Spatial Step		as low as 5 cm		
Temperature Range		-270 °C to +2100 °C (depending on cable material)		
Strain Range		-3% (compression) to +4% (elongation) (depending on cable material)		
Temperature Resolution		0.005 °C ³		
Temperature Accuracy (2σ)		± 0.1°C (Whole sensing range for BOTDA)		
Strain Resolution		0.1 µε ²		
Strain Accuracy (2σ)		± 2 µε (Whole sensing range for BOTDA)		
Acquisition Time (full scan)		as low as 1 second		
Averaging		1 to 65,000 scans		
Fault Point Detection	Acquisition Time	1 second per thousand scans		
	Sensing Range (round trip)	100 km		
Simultaneous Measurement of Strain and Temperature (using patented cable design)	Temperature Resolution	0.005°C ²		
	Temperature Accuracy (2σ)	± 0.1°C (Whole sensing range for BOTDA)		
	Strain Resolution	0.1 µε ²		
	Strain Accuracy (2σ)	± 2 µε (Whole sensing range for BOTDA)		
Measured Variables		Strain and/or temperature, Brillouin spectrum		
Communication & Connections		Ethernet port, USB		
Output Signals		Software alarms via TCP/IP, SPST, SSR relays (optional)		
Data Storage		Internal hard disc (128 GB or more)		
Data Format		Database, text files, MS Excel, bitmap plot		
Optical Connections		FC/APC ⁴		
Laser Wavelength		1550 nm band		
Operating Temperature		0 °C to 40 °C, <85% RH, Non-condensing		
Power Supply		115 or 230 VAC; 50-60Hz; max 300W		
Dimensions (L x W x H)	3U Chassis	390 mm x 344 mm x 133 mm (not including computer) ⁵		
Weight	3U Chassis	<12 kg (not including computer)		
Measurement Modes		Manual, remote or automatic unattended measurements		
Data Analysis		Measurement analysis, multiple trace comparison with respect to selectable baseline, measurement trends, graphical zoom		
Alarm & Warnings		Automatic alarm triggering, configurable alarm settings (heat, threshold, etc.)		
Remote Operation		Remote control, configuration and maintenance via TCP/IP		
Watch Dog		Long term operation 24/7 guaranteed by automatic recovery and continuous self diagnostics		

¹ 2 channels or 4 channels are provided within the sensor unit. Additional channels can be added by using an external optical switch.

² Better spatial resolution is optional.

³ This value is estimated/calculated from the uncertainty of laser beat frequency (5 kHz), and temperature and strain coefficients of fibers.

⁴ Adaptors and patch cords are available for mating with other types of optical connectors.

⁵ Dimensions do not include carrying handle. Air vents on sides of unit must not be obstructed.

Related Products

Fiber Optic Sensor Probes, Components, Termination Kits, and Training

OZ Optics offers a full spectrum of fiber optic sensor probes, components, termination kits and training. OZ Optics' standard fiber optic products have been used worldwide in high performance sensor and telecommunications applications since 1985. OZ Optics also offers specialty fiber optic sensor probes and custom cabling for high temperature applications and other hostile and corrosive environments. System integrators with experience in structural and pipeline monitoring will find that OZ Optics offers a complete suite of enabling products and services for installing and maintaining fiber optic systems. If you are planning a pipeline or structural monitoring project, please contact OZ Optics to learn more about our fiber optic solutions.

For more information about our strain and temperature sensor systems and related products, please visit www.ozoptics.com.

Ordering Information

Part Number Description: **DSTS-CT CO I-SR-MSR-AS-BOTDA-X-CH**

CT = Chassis Type of DSTS
opto-electronics box
3U = 3U chassis

CO = Computer Type
L = Laptop (requires 3U chassis)
X = Customer supplier computer

I = Internal Interface between DAQ and
computer
T = Thunderbolt (requires 3U chassis)
S = Standard

SR = Spatial Resolution (m)¹
1/10
1/50

CH = Number of channels
2CH = 2 built-in channels
4CH = 4 built-in channels

X = Connector Type
3A = FC/APC

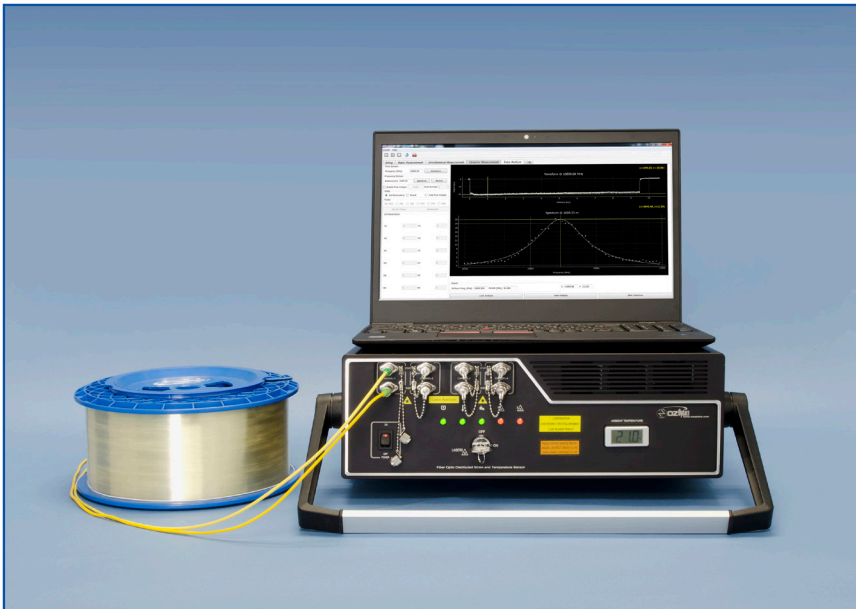
AS = Acquisition Speed³
N = Normal
H = High Speed

MSR = Maximum Sensing Range (km)^{1,2}
60
100

For a field-ready unit, replace the chassis type, computer type, and computer interface with a single letter "F." Field ready units include a built-in computer, monitor, keyboard and mouse.

Notes:

- Each BDTS can be configured for short haul operation, long haul operation or both. The configuration must be specified at the time of purchase. The spatial resolution indicates the best resolution at the maximum sensing range. If the BDTS is configured for both short-haul and long-haul measurements then two numbers will be listed indicating the resolutions and maximum sensing range for each operating mode. For example, suppose the BDTS unit needs to achieve 1 meter resolution over a 10 km range for short-haul applications, and 50 meter resolution over a 100 km range for long-haul applications. The part number will specify the spatial resolution (SR) as 1/50, and maximum sensing range (MSR) as 100.
- Maximum sensing range is 60 km or 100 km for long haul operation.
- The acquisition speed is described as normal or high speed. N and H are used respectively. The high-speed version is typically at least a factor of two faster than the normal-speed version during the acquisition of data.



3U model with laptop computer

The 3U version of the BDTS comes with removable carrying handles. The user can easily replace the handles with tabs (sold separately) that will allow the unit to be installed in a standard 19-inch rack.

Optional Accessories



Fiber fusion splicer - FSP-100-S/M



Precision fiber cleaver - FSP-100-CLV

Optional Accessories

Bar Code	Part Number	Description
74023	DSTS-TRAVEL-CASE-3U	Plastic travel case for 2U or 3U DSTS unit, with extendable pull handle and wheels. Designed for checking on airplane. Approximate dimensions: 23.75 (H) x 22.5 (W) x 15 (D). {60.3 cm x 57.2 cm x 38.1 cm}.
65518	FIBER MICROSCOPE HANDHELD	Handheld Video Microscope kit for Fiber Optic Connector Inspection. The kit includes an LCD display with video probe. An AC power adapter with battery charger and a rechargeable battery pack is included. Several common adaptor types come with the unit, including an SC/FC PC female adaptor and an LC/PC female adaptor.
48980	CI-1100-A2-PT2-FS/APC/F	Tip for SC and FC APC type female (in receptacle) connector for CI-1100-A2 handheld microscope.
36939	HUXCLEANER-2.5	Receptacle fiber cleaner for FC, SC and ST types.
5336	Fiber-Connector-Cleaner-SA	Disposable Cletop reel type A optical fiber connector cleaner.
8122	SMJ-3A3A-1300/1550-9/125-3-1	1 meter long, 3 mm OD jacketed, 1300/1550 nm 9/125 μ m Corning SMF 28e fiber patchcord, terminated with angled FC/APC connectors on both ends.
11	PMPC-03	Flanged sleeve thru connector for polarization maintaining FC/PC connectors. Keyway width is 2.03/2.07 mm wide for 2.00 mm wide (Type R) key connectors.
19711	AA-200-11-9/125-3A3A	Universal connector with a male angle FC/APC connector at the input and a female angle FC/APC receptacle at the output end for SM 9/125 applications.
58975	DSTS-3U-19IN-RACK-MOUNT-KIT	Brackets with handles & hardware to convert 3U DSTS to 19" rack mountable version.
77982	FSP-100-S/M	Fiber fusion splicer for singlemode and multimode fiber, featuring fiber core alignment and automatic fiber identification (singlemode vs multimode) for optimum splice loss. Suitable for bare fibers, patch cords, drop cables etc. A fiber cleaver and fiber stripper is included with the unit as a kit.
77984	FSP-100-CLV	Precision fiber cleaver for fusion splicing, with automatic blade rotation for maximum lifetime.

Questionnaire

1. What is your application? Please describe briefly.
2. Are you looking for a BOTDA module (requires both ends of fiber to be connected to DSTS) or a BOTDR module (requires only one end of fiber to be connected to DSTS) or a COMBO unit with both BOTDA and BOTDR functions?
3. What are your resolution and precision requirements for temperature measurements?
Resolution: _____
Precision: _____
4. What are the highest and lowest temperatures you expect?
5. What are your resolution and precision requirements for strain measurements?
Resolution: _____
Precision: _____
6. What is the maximum strain to be measured?
7. What is the desired sensing range or fiber length in this application?
8. What spatial resolution do you desire?
9. Do you want to measure temperature, strain or both?
10. What is the desired data acquisition time?
11. Do you need fiber calibration / system design / project engineering service?
12. Where will the unit be housed?
13. Do you need a portable model with a laptop computer or a 19" rack-mounted model with a laptop computer?
14. Any additional information?

Please email sales@ozoptics.com for our recommendation about your requirements.

The BOTDA technique is significantly more powerful as it uses enhanced Brillouin scattering through two counter-propagating beams. Due to the strong signal strength the strain and temperature measurements are more accurate and the measuring range is longer than that of BOTDR technology. In addition, our patented sensing method allows one to determine simultaneous strain and temperature information.

The BOTDA method requires more optical components and a 2-way optical path so the total system cost is typically higher (the sensor fiber must be looped or mirrored). However, most field units deployed today are BOTDA systems because the additional measurement accuracy more than justifies the moderate increase in system cost.

OZ Optics' Foresight™ series of DSTS has BOTDA, BOTDR and BOTDA/BOTDR combo units. Our customers can enjoy more choices based on their special requirements. Table 1 provides a comparison of common fiber optic strain and temperature sensor techniques, along with typical performance limits for each type:

	Bragg Grating*	BOTDR	BOTDA
Strain Accuracy	± 1 µstrain	± 16 µstrain	± 2 µstrain
Spatial Resolution	0.1 m	1 m	0.1 m
Length Range	Point sensor	70 km	100 km
Acquisition Time	<1 second	3–20 minutes	As low as 1 second
Configuration	Many fibers	Single fiber	Loop or single fibers
Temperature Accuracy	± 0.4°C	± 0.8°C	± 0.1°C
Strain and Temperature	Multiple fibers	Multiple fibers	Single or multiple fibers
Distributed	No	Yes	Yes
*quasi-distributed with multiple fibers			

Table 1. Typical Performances of Distributed / Quasi Distributed Fiber Optic Sensors

The simultaneous measurement of strain and temperature is possible by using our patented method. Standard singlemode fiber is used in large quantities for high speed optical telecommunications networks and is inexpensive. It is important to make a decision on the fiber type and cable structure early in any structural monitoring project. Although test equipment can be changed or upgraded in the future, it is essential to install the correct fiber type if the simultaneous measurement of strain and temperature is required.

Major Applications of Fiber Optic Distributed Strain and Temperature Sensors

Fiber optic distributed strain and temperature sensors have been applied in numerous applications. As mentioned previously, Brillouin-based systems are generally unmatched in applications that require high-resolution monitoring of large structures (long, or large surface areas). Unlike competing sensor technologies, Brillouin systems directly leverage the economies of scale from the millions of kilometers of fiber optic telecommunications fiber installed worldwide. As Table 2 shows below, the most common applications for distributed strain and temperature sensors involves very large linear or spatial dimensions.

Application	Strain	Temperature	References available upon request by OZ Optics collaborators
Pipeline Leakage Monitoring	■	■	■
Power Lines Monitoring	■	■	■
Process Control	■	■	■
Structural Health Monitoring (concrete & composite structures)	■		■
Bridge Monitoring	■	■	■
Fire Detection	■	■	■
Crack Detection	■		■
Security Fences	■		

Table 2. Applications of Brillouin Fiber Optic Sensors

OZ Optics is committed to delivering solutions in each of the markets listed above. If your critical monitoring application is not listed in the table, please contact us with your requirements. To get more detailed information related to your application or request a reference article, please contact OZ Optics.

The fiber optic strand provides excellent flexibility and placement over large areas and great distances. For example: a mining conveyor belt may be tens of kilometres long in order to remove excess debris. The material is of little value and detecting a seizing bearing along the length would be difficult via conventional fire detection means. As a bearing starts to seize, it will overheat prior to causing a fire. The DSTS and sensing fiber is easily installed and will readily detect this change in heat at a bearing. While the direct cost of the damage caused by the fire is minimal, the loss of revenue from shutdown of the mining operations while the conveyer belt is repaired will be extensive.

Sample Performance Table

Distributed Brillouin measurements are quantified by four variables: precision of measurement, variation of strain and temperature to be measured, spatial resolution, and length of fiber being measured. These four interact to determine the time the measurement will take. Conversely, if time is restricted, the other qualities of measurement can be determined.

The ForeSight™ Brillouin based DSTS BOTDA module design enables focus on the variable of most concern. For instance, concrete fracture detection may require tight spatial resolution and high precision. The result will be a known measurement time and the maximum fiber length that can be utilized.

The measurement time can vary from 1 second to 10 minutes based up the requirements dictated by the application. The sample table below reflects some common requirements: better than $\pm 0.5^\circ\text{C}$ and $\pm 10 \mu\epsilon$ precision. All table measurements were completed in less than 1 minute and 40 seconds.

The table is not a restriction of what can be achieved. Variations in the four areas of concern can be accommodated. For instance, the measurement of temperature/strain for 50 km sensing fiber, 2 m spatial resolution, with an accuracy of $0.2^\circ\text{C}/4 \mu\epsilon$ is attainable, but will increase measuring time to 3 minutes and 45 seconds. Another comparison of the interaction of fiber length, spatial resolution, accuracy of temperature/strain, and measurement time: 100 km sensing fiber, 6 m spatial resolution can be $0.4^\circ\text{C}/8 \mu\epsilon$ when measuring time is 4 minutes and 38 seconds, however the same 100 km can have a precision of $0.1^\circ\text{C}/2 \mu\epsilon$ when spatial resolution is increased to 50 m with a measuring time of 3 minutes and 48 seconds.

		Spatial Resolution									
		10 cm	50 cm	1 m	2 m	3 m	4 m	5 m	10 m	20 m	50 m
Fiber Length	1 km	0.3°C/6 $\mu\epsilon$	0.2°C/4 $\mu\epsilon$								
	2 km		0.3°C/6 $\mu\epsilon$	0.1°C/2 $\mu\epsilon$							
	4 km		0.4°C/8 $\mu\epsilon$	0.3°C/6 $\mu\epsilon$							
	10 km			0.3°C/6 $\mu\epsilon$							
	20 km			0.4°C/8 $\mu\epsilon$	0.06°C/1.2 $\mu\epsilon$						
	30 km				0.2°C/4 $\mu\epsilon$						
	40 km				0.3°C/6 $\mu\epsilon$	0.1°C/2 $\mu\epsilon$	0.2°C/4 $\mu\epsilon$				
	50 km					0.2°C/4 $\mu\epsilon$	0.3°C/6 $\mu\epsilon$	0.2°C/4 $\mu\epsilon$	0.1°C/2 $\mu\epsilon$		
	60 km								0.2°C/4 $\mu\epsilon$		
	70 km								0.3°C/6 $\mu\epsilon$		
	80 km									0.2°C/4 $\mu\epsilon$	
	90 km									0.4°C/8 $\mu\epsilon$	
100 km									0.4°C/8 $\mu\epsilon$	0.2°C/4 $\mu\epsilon$	

Table 3. Typical BOTDA module measurement precision table (Acquisition time ≤ 100 seconds)

Fast Measurement Mode

The DSTS BOTDA can be used in a fire detection and control system. The distributed fiber optics technology provides for excellent flexibility to detect fires. The fiber optic strand does not pose a spark risk or explosion risk, and if properly designed, it may be placed in an area subject to ionizing radiation. The spatial resolution is dependent on the fiber length. With a 20 km fiber length, a spatial resolution of 1 m is provided. Shorter lengths can be monitored with better spatial resolution, compared to longer fibers. Similarly, longer lengths can be monitored at the expense of resolution. Refer to Table 3 for more details.

Temperature measurement performance while in Fast Measurement Mode will vary from a nominal Brillouin measurement in that the goals of the measurement are based upon fast detection of a change in temperature. The overall goal of the Fast Measurement Mode is to accurately detect a change in temperature associated with a pending fire or outright temperature changes in a nominal amount of time. Therefore the performance of the DSTS BOTDA will meet or be better than the following table:

Start Temperature	Required Measuring Temperature By System	Oven Setting Temperature	Specified Measurement Time	Measurement Accuracy
24°C	30°C	30°C	9 sec	28 - 32°C
24°C	40°C	40°C	11 sec	38 - 42°C
24°C	50°C	50°C	13 sec	48 - 52°C
24°C	60°C	60°C	14 sec	58 - 62°C
24°C	70°C	70°C	16 sec	68 - 72°C
24°C	80°C	80°C	18 sec	78 - 82°C

Table 4. Typical Accuracy for Fire Detection Applications (Fast Measurement Mode)

The following conditions apply for the reference table to be accurate:

- Total fiber length: 60 km
- Spatial resolution: 6 m
- Baseline must be obtained at 24°C before temperature measurements.
- Measurement time does not include sensing cable response time.
- All sensing fiber must be same type of fiber without strain effect.

Calculating the Cost Savings for Brillouin Fiber Optic Sensors

As stated previously, Brillouin fiber sensors offer high-resolution with long distance coverage at a cost per kilometer unmatched by any other measurement technique. This creates the opportunity to generate a rapid return on investment for Brillouin sensor-based monitoring systems used in critical monitoring applications. The figure below shows a simple cost savings example:

Fiber Optic Monitoring OZ Optics Ltd. Cost Savings Calculator				
System Parameters				
Pipeline Length	50 km			
Cost of Failure	\$750,000 cost of leak			
Downtime Cost	\$20,000 per hour			
Comparison		Monitoring	No Monitoring	Comments
Probability of Failure	% / year	0.25%	1%	Reduced risk of failure
Downtime	hours/year	4.8	24	Automated preventive maintenance
Maintenance Cost	dollars/year	\$25,000	\$50,000	Automation of routine maintenance
Total Annual Savings		\$414,625		Total Annual Savings

Table 5. Cost Savings example

Several pipeline shutdown accidents demonstrate the need for continuous online monitoring. While the calculation in Table 5 is for a mid-sized regional distribution pipeline, the economics for major pipelines are even more compelling. The shutdown cost per day can easily exceed \$10 million. With long-haul Brillouin monitoring system costs of only \$1 - \$2 per meter, the prevention of a single shutdown greatly exceeds the installation and operating costs of a monitoring system. Other large structures such as power lines, dams, and bridges also have very high costs associated with catastrophic failure and shutdowns.

The most important factors in a typical cost savings estimate are the reduction in maintenance/inspection cost (due to automated monitoring), the reduction in downtime, and the reduction in the potential for catastrophic failure. In many instances, the downtime and failure costs are much higher than that shown in the example.

For more information about our strain and temperature sensor system and related products, please visit www.ozoptics.com.

Background Articles

Pipeline Buckling Detection:

L. Zou, X. Bao, F. Ravet, and L. Chen, "Distributed Brillouin fiber sensor for detecting pipeline buckling in an energy pipe under internal pressure," *Applied Optics* 45, 3372-3377 (2006).

Pipeline Corrosion Detection:

L. Zou, G. Ferrier, S. Afshar, Q. Yu, L. Chen, and X. Bao, "Distributed Brillouin scattering sensor for discrimination of wall-thinning defects in steel pipe under internal pressure," *Applied Optics* 43, 1583-1588 (2004).

Power Line Monitoring:

L. Zou, X. Bao, Y. Wan and L. Chen, "Coherent probe-pump-based Brillouin sensor for centimeter-crack detection," *Optics Letters* 30, 370-372 (2005).

Crack Detection:

L. Zou and Maria Q. Feng, "Detection of micrometer crack by Brillouin-scattering-based distributed strain and temperature sensor," 19th International Conference on Optical Fiber Sensors, Perth (Australia, 14-18 April 2008).

Accuracy of BOTDA Technology:

L. Zou, X. Bao, S. Yang, L. Chen, and F. Ravet, "Effect of Brillouin slow light on distributed Brillouin fiber sensors," *Optics Letters* 31, 2698-2700 (2006)

Simultaneous Measurement of Strain and Temperature:

L. Zou, X. Bao, S. Afshar V., and L. Chen, "Dependence of the Brillouin frequency shift on strain and temperature in a photonic crystal fiber," *Optics Letters* 29, 1485-1487 (2004)