HAZARD MONITORING IN MINES USING FIBER OPTIC SENSORS

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OUTLINE

- Background - Mine Hazards
- FOS based Intelligent Mine Safety Monitoring Systems
  - Roof condition and water burst monitoring
  - Early fire detection
    - Power safety monitoring
    - Spontaneous fire early warning
  - Methane gas monitoring
  - Field trials: coal mines, tailings dam landslide
  - Summary

CHINESE COAL MINE INDUSTRY

- Coal provides majority of the energy (>70%);
- Annual Production: ~3 billion tons,
- ~ 1/3 of world coal production;

- Number of coal mines: ~15,000
- - State and local government own ~3,000, the rests are small mines;
- Used to be >70,000 mines
- Key Issue: SAFETY

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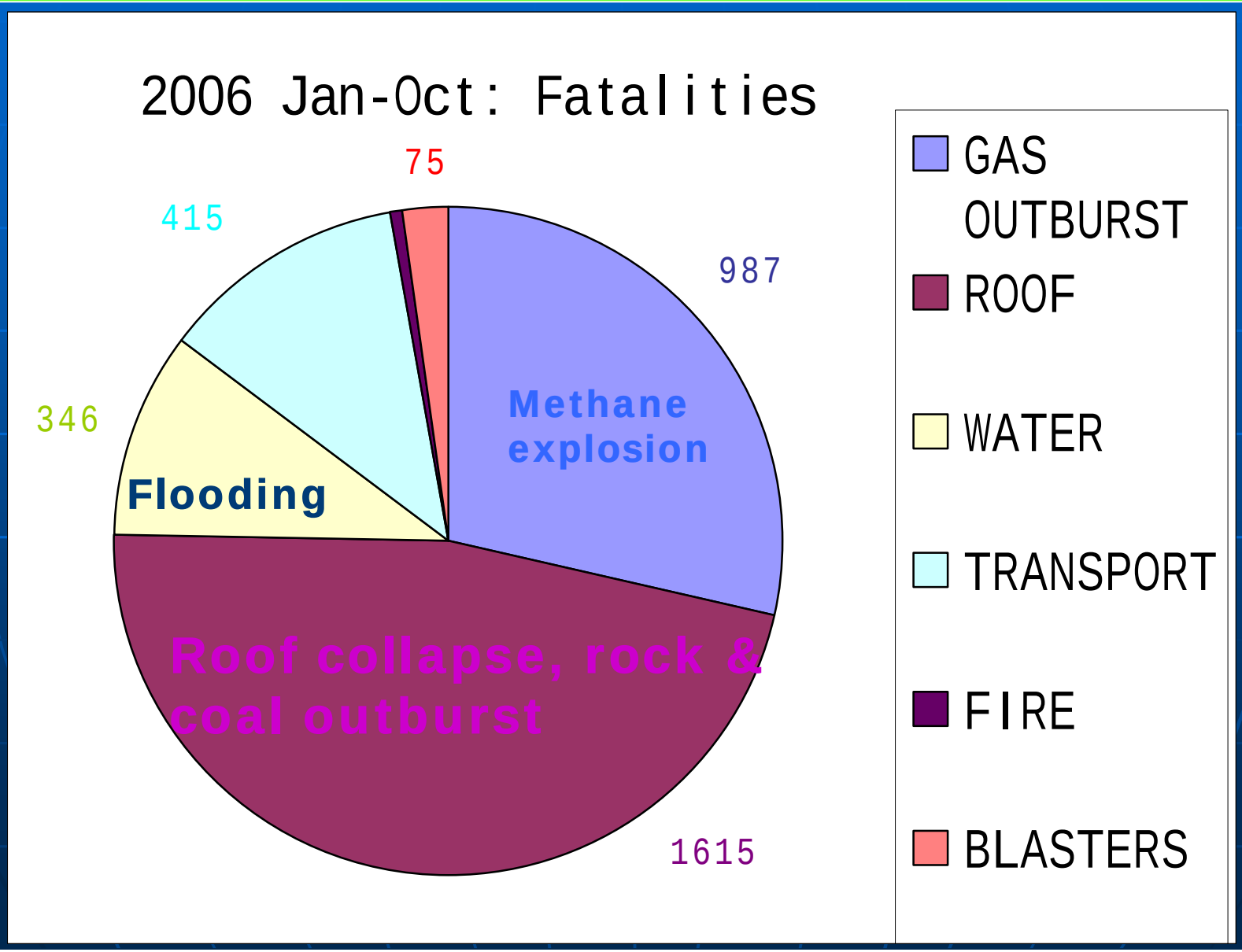
COAL MINE SAFETY

- 2001-2005:
  - Number of coal mine accidents:18,516
  - Number of death: 31,064 (AVE: 17 per day !)
  - In recent years, both the government and the mine operators invested heavily on safety technologies, the fatality rate dropped, but total number still very high.
- FATALITIES DUE TO EXPLOSION:
  - State owned mine groups have world class safety standard;
  - However, in small mines **casualty rate** over 100 times higher.

MAJOR COAL MINE HAZARDS



MOTIVATION

- To develop a comprehensive mine disaster management system based on fiber optic sensor network,
- Capable of mining hazard early warning and control.

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PRINCIPLE

- Various mining hazards are inter-linked, they do not happen alone;
- Detectable symptoms exist prior to disasters happen.

ROOF COLLAPSE, ROCK BURST

- Large area of roof sudden collapses,
- thousands of tons of rock and coal burst out
- casualties and struct damages.

MINE ROOF DEFORMATION

- Roof monitoring: roof displacement, seismic, not compulsory:
- Resistance strain gauges, suffer drifts, often off line…

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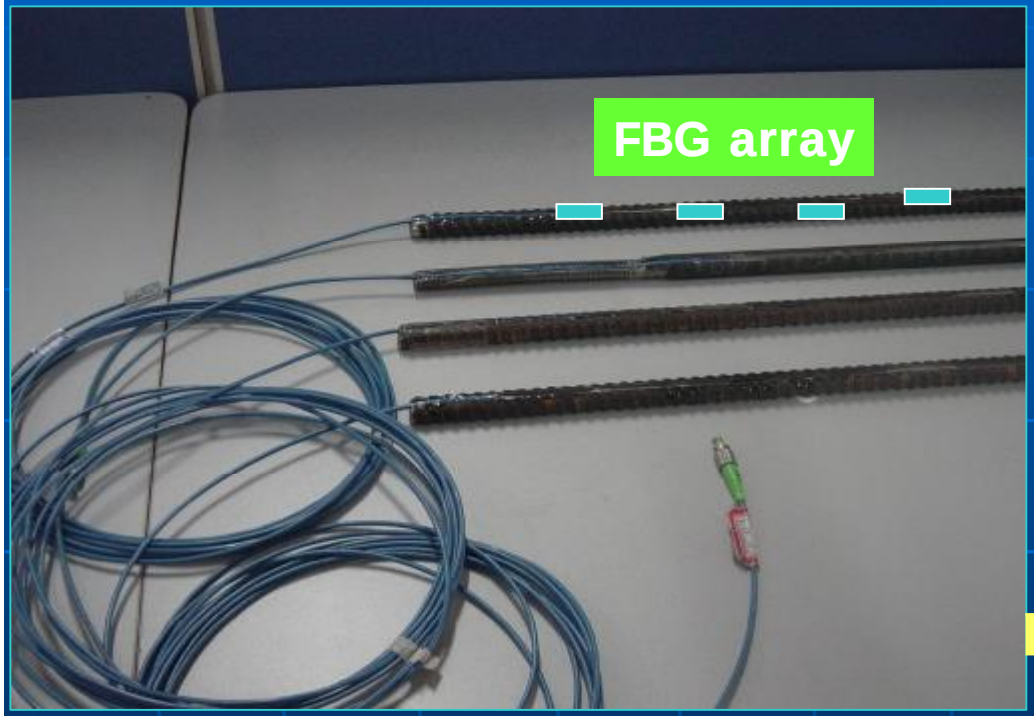
Rock Strain, Roof Displacement Sensors



n FBG rock strain sensor array on steel bar

n FBG roof displacement sensor,
n *d* transferred to FBG strai

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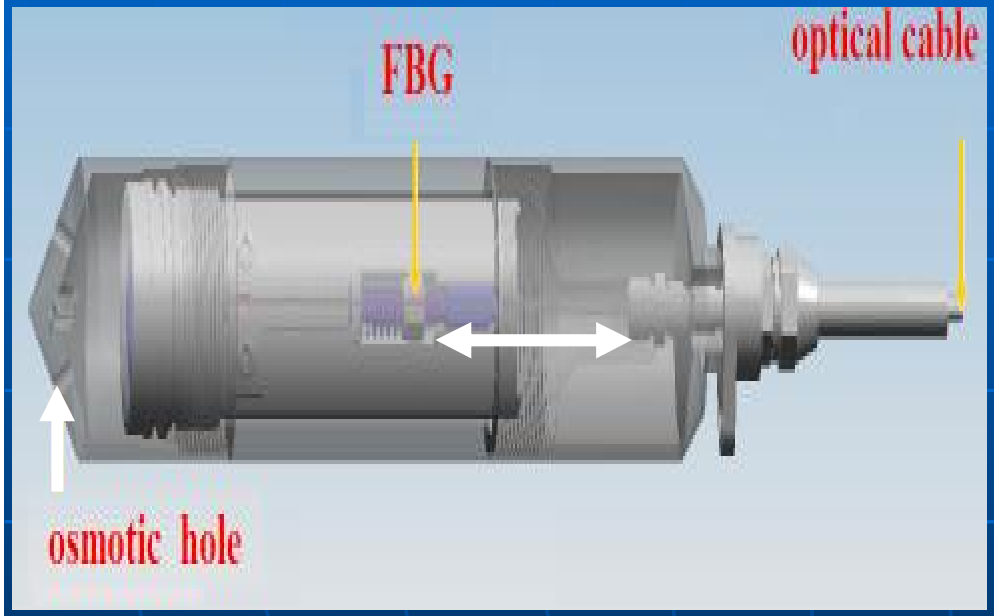
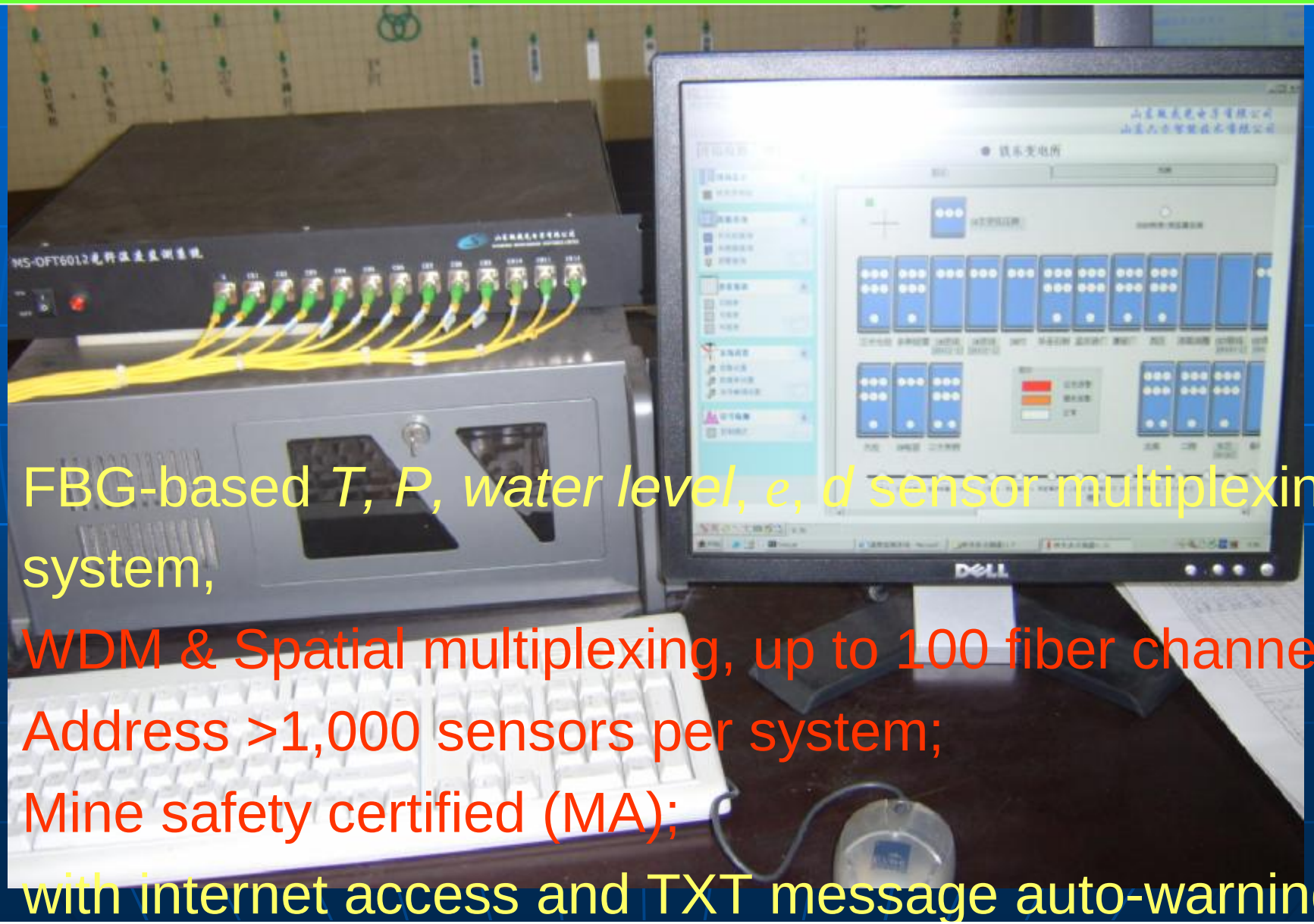
Sensors for Water Burst Detection



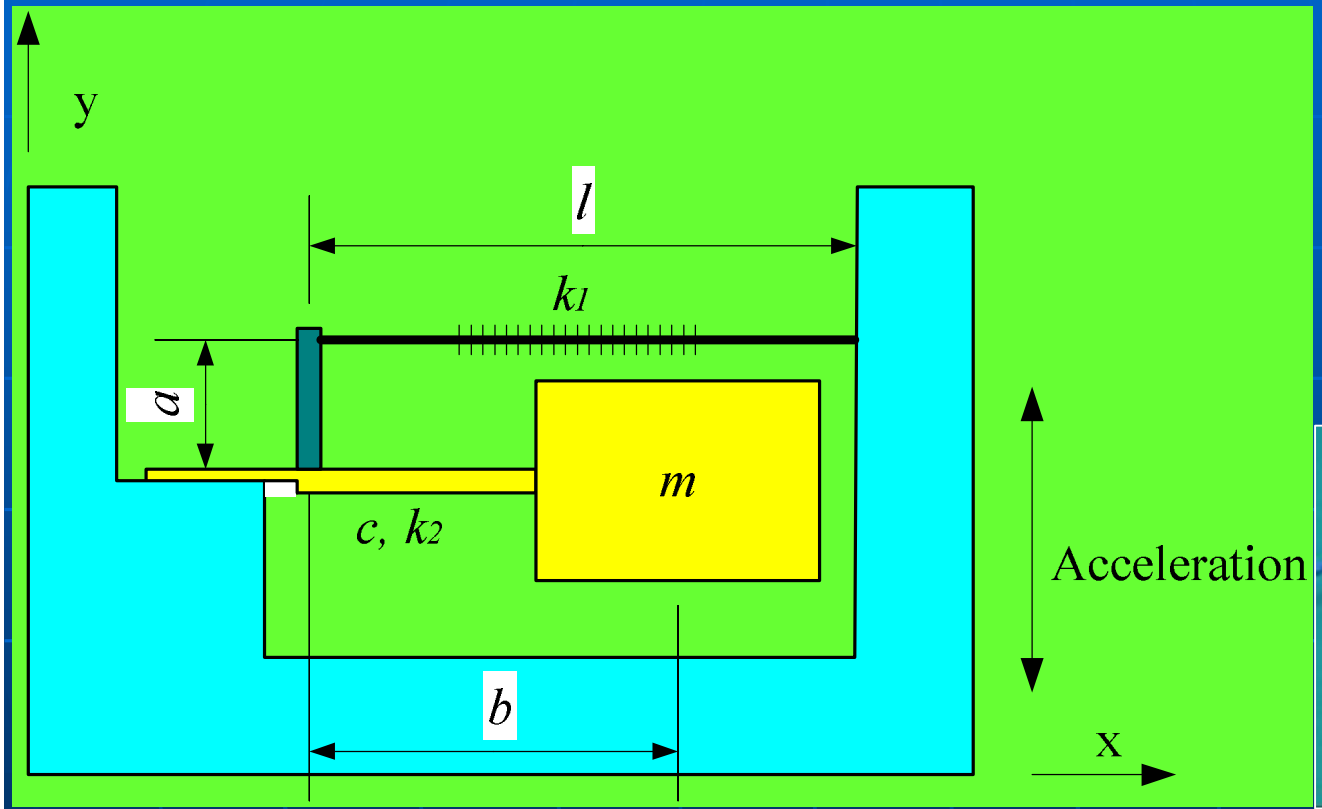
- FBG Pressure sensor with built-in temperature sensor;
- For mineral mine safety application, where major hazards are water flooding, tailing dam, and roof fall.

Multi-Parameter FBG Sensor Sys.



- FBG-based *T, P, water level*, *e*, *d* sensor multiplexing
- system,
- WDM & Spatial multiplexing, up to 100 fiber channels,
- Address >1,000 sensors per system;
- Mine safety certified (MA);
- with internet access and TXT message auto-warning.

MICRO-SEISMIC SENSOR



- Cantilever based accelerometer:
- Acceleration results in mass displacement, then FBG strain variation

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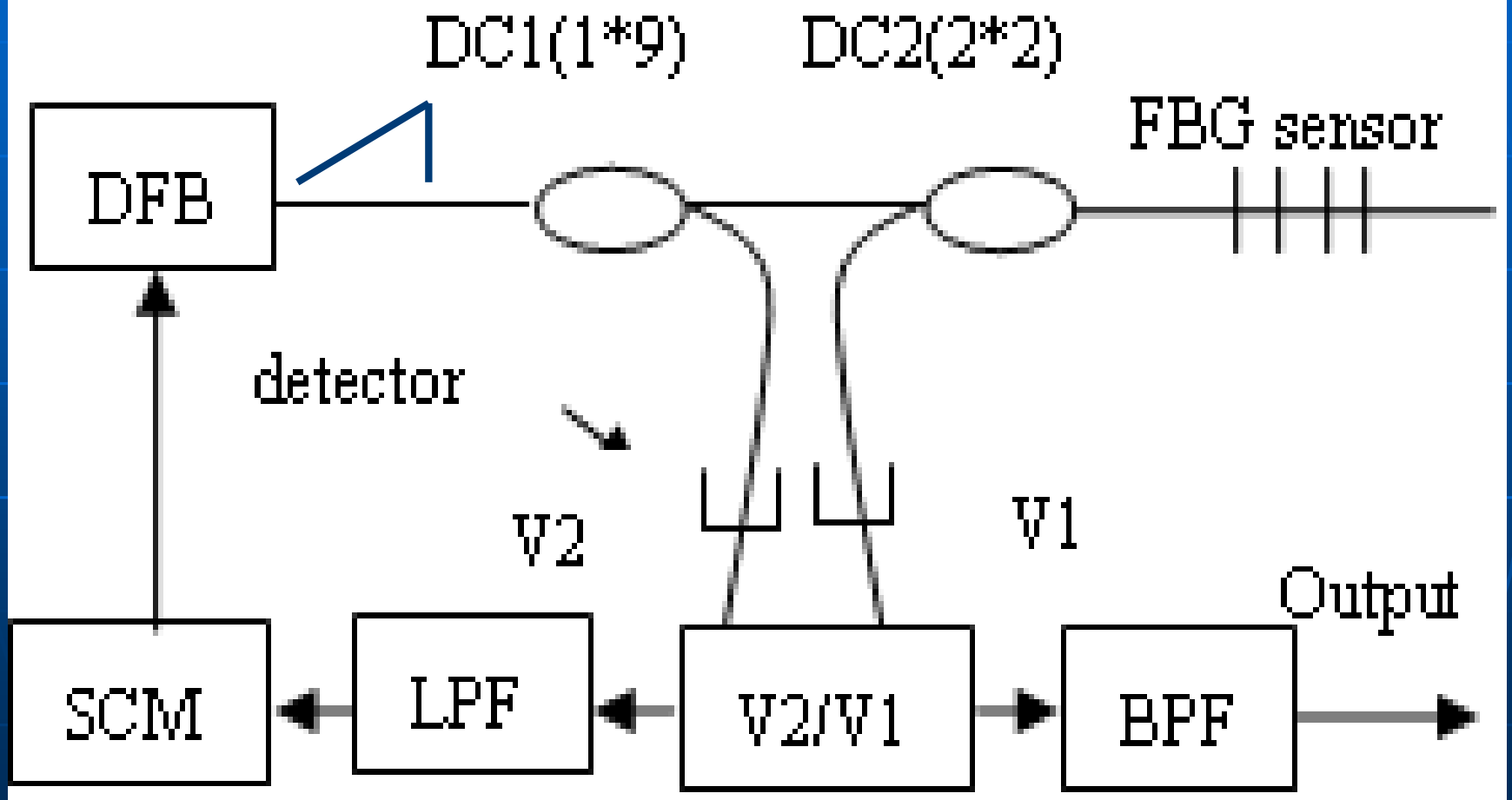
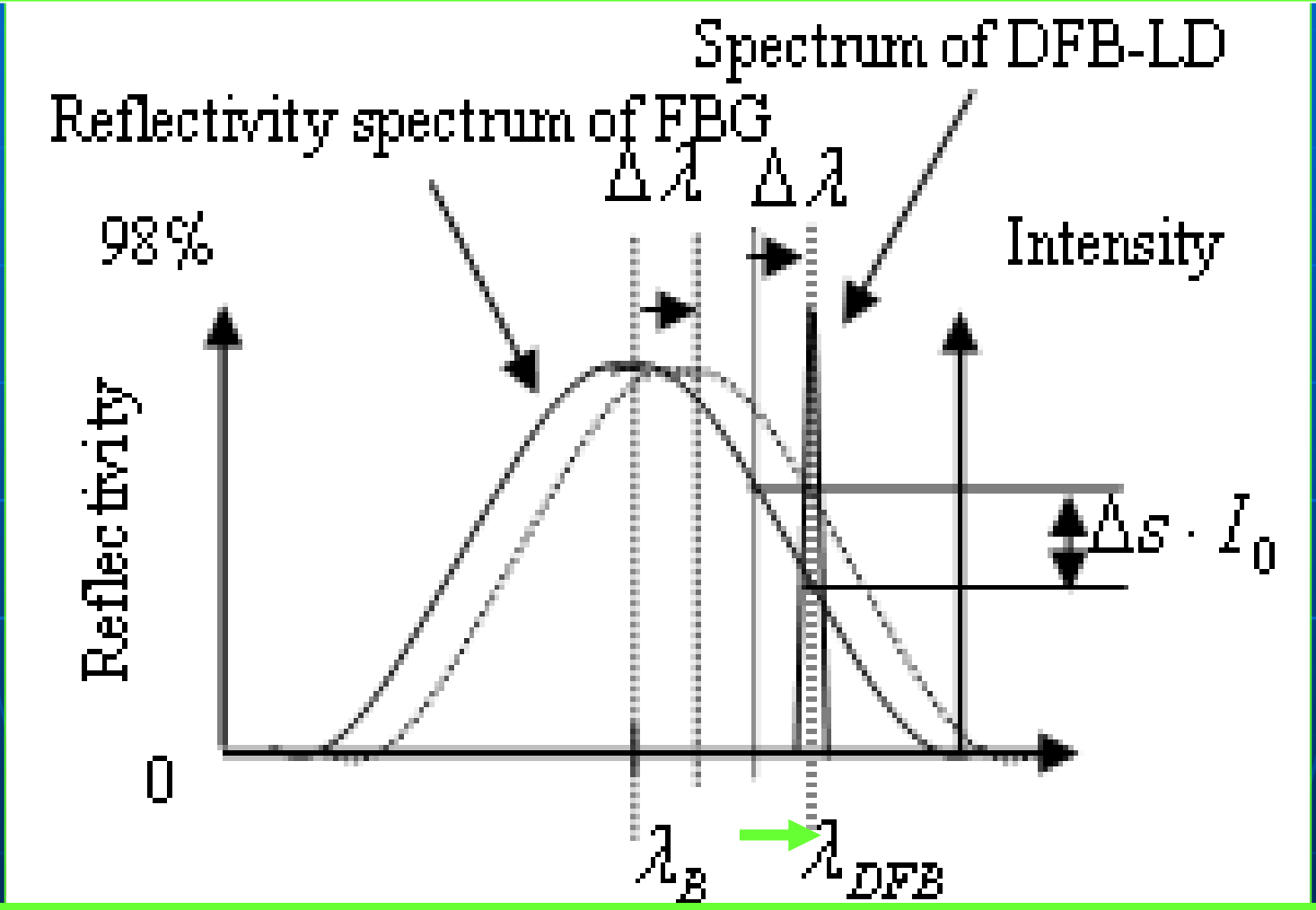
Micro-Seismic Sensor Interrogation

1. Saw-tooth laser current sweep to locate FBG reflect. Spectrum



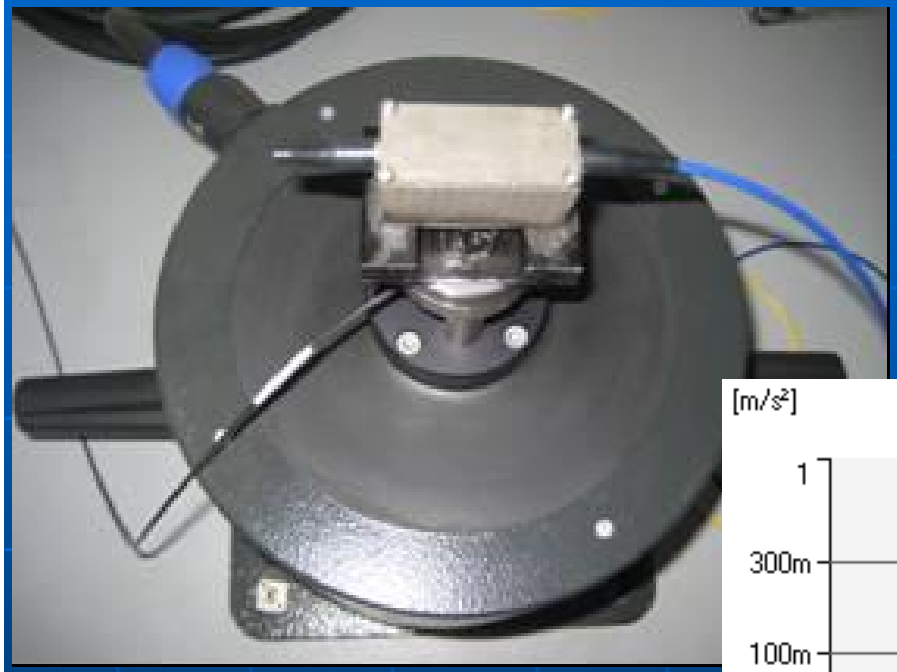
2. SCM PID control to lock the DFB LD to -3dB point in the FBG spectrum.

Micro-Seismic Sensor Interrogation

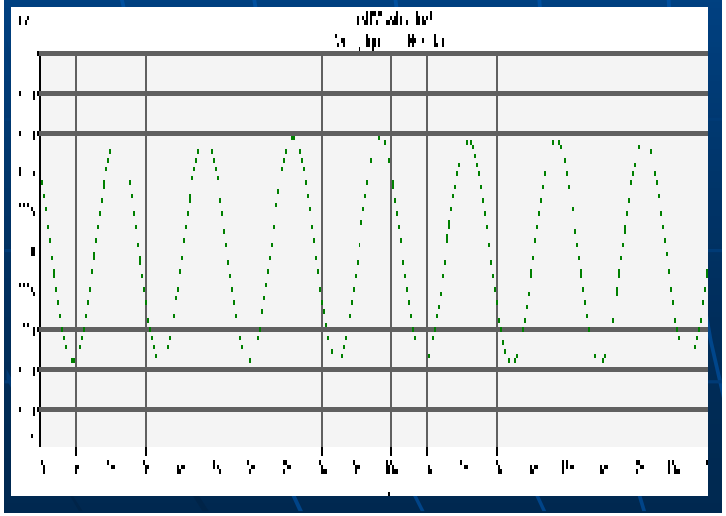


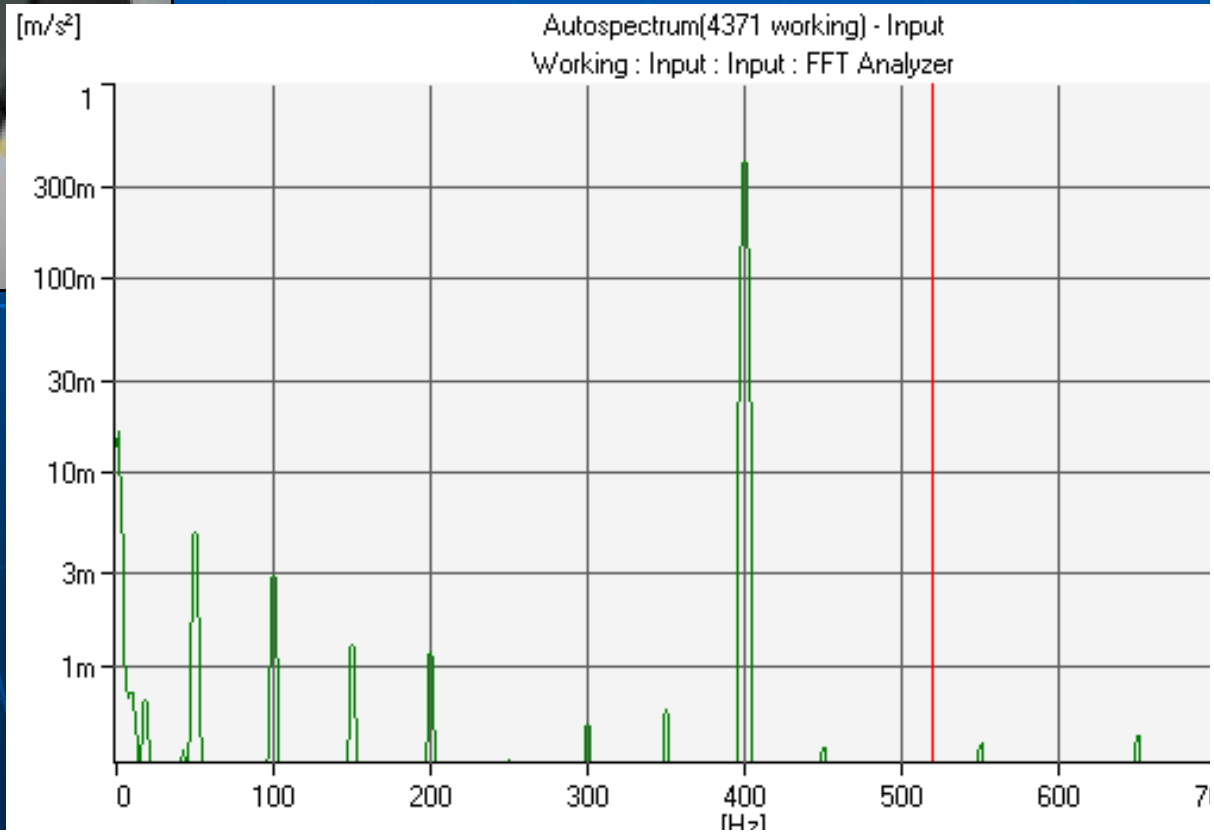
- FBG edge to give acceleration signal;
- PID LD current lock to track FBG slow drift.

Micro-Seismic Sensor Character.



- Sensitivity: 0.1mg;
- Range: 0-10g.
- BW: 3-400 Hz
- Auto-drift compensation





COAL MINE FIRE

- 2008.09 Hegang Spontaneous coal fire causing 19 people died;

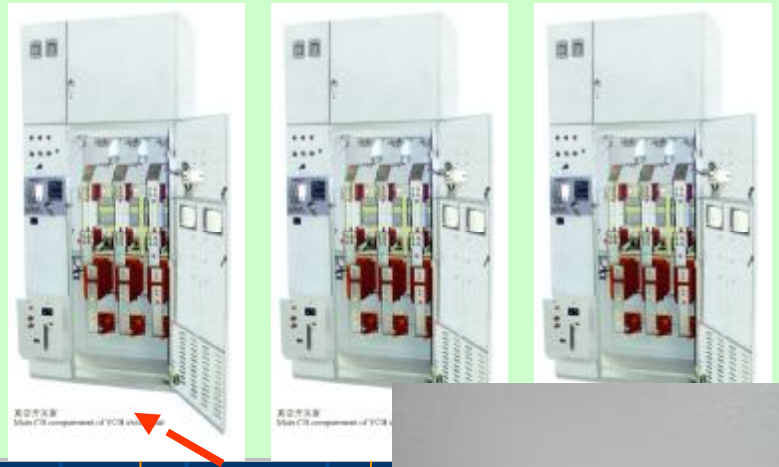
- **2007.02 Henan Province, 17 died in a power cable joint overheat caused fire.**

Mining Power Station Condition Monitoring

Internet server

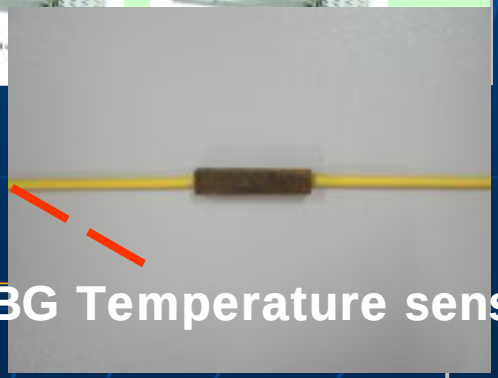
FBG Interrogator

On-line high voltage switchgear temperature monitoring



Fiber connection

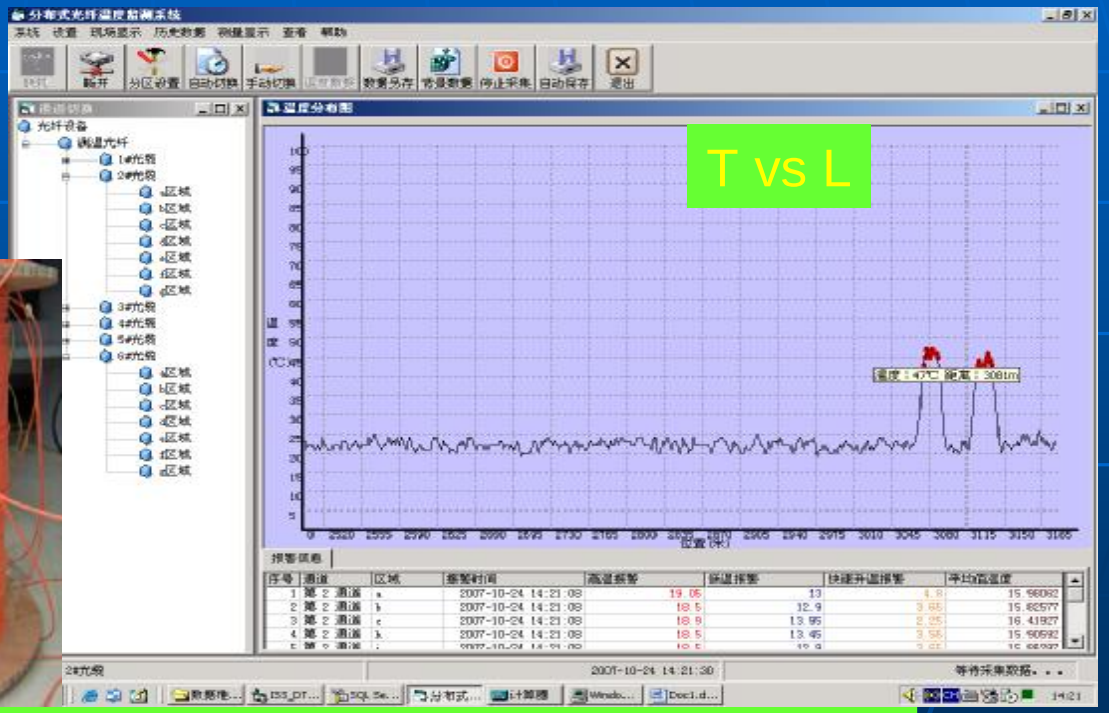
Optical fiber cable



FBG Temperature sensor

Fire Prediction and Location

- **6-10 km range**



- Raman DTS
- T Monitor and fire warning
- location system

- armoured cable for underground mined-out area;
- along power cable.

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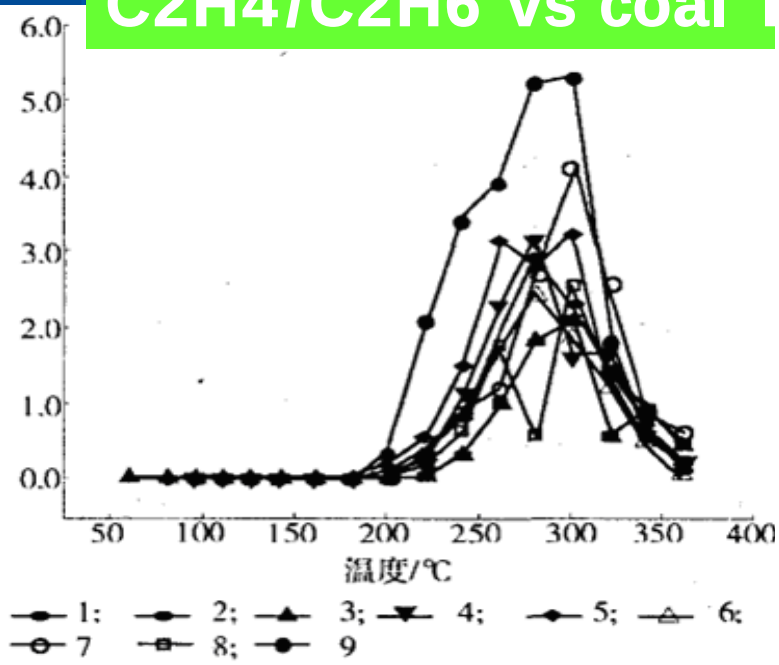
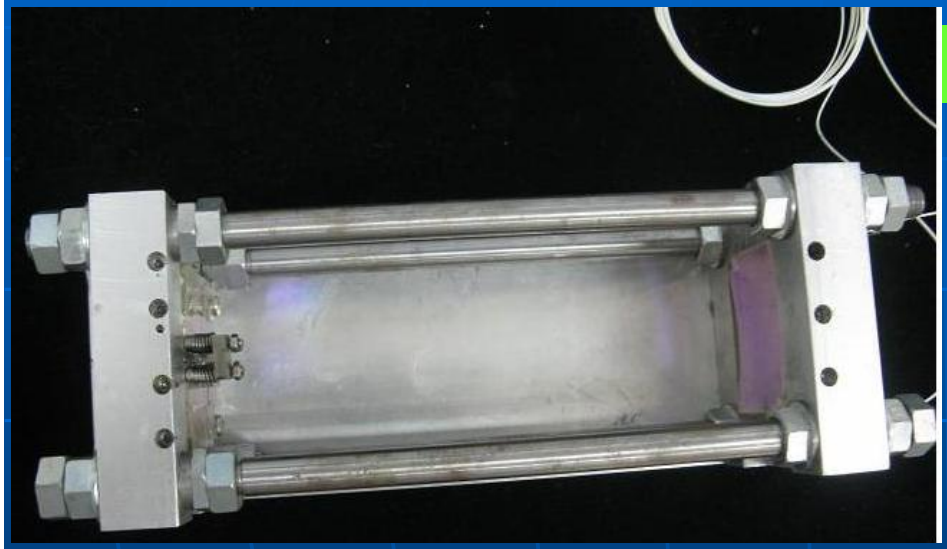
Spontaneous Coal Mine Fire Detection

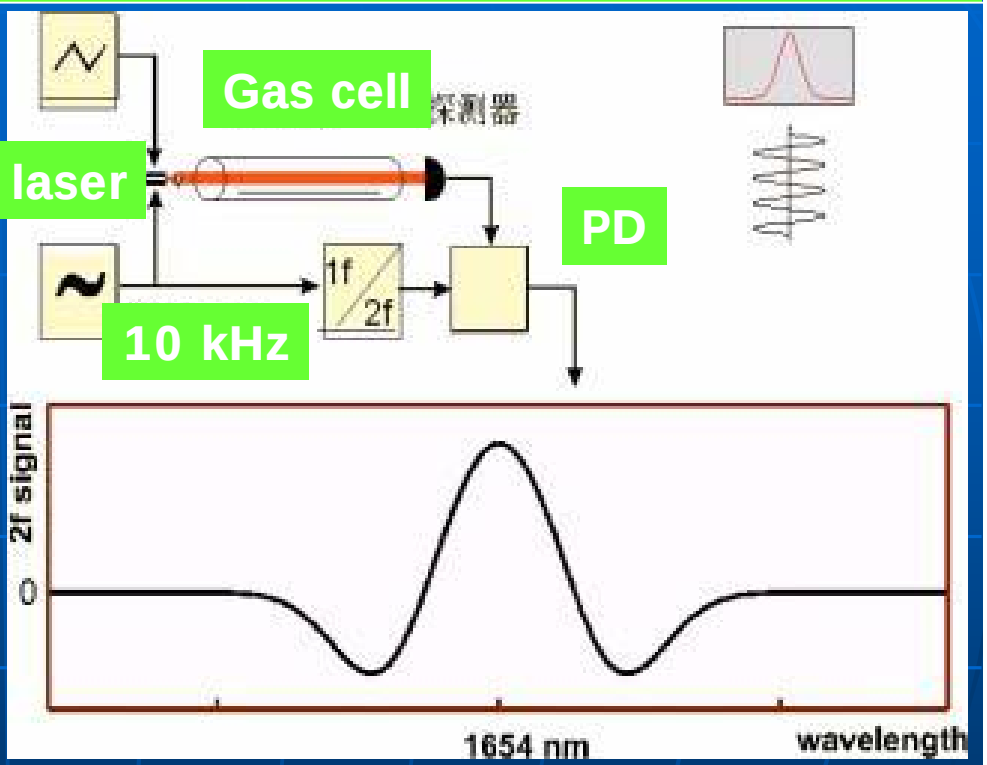
- Underground spontaneous coal fire can occur as soon as 14 days after production production;
- Early detection can be made by monitoring CO (@1567nm), CH_4 (@1665nm) and C2H4 (@)1630nm; O2 (@762nm);
- Ratio of CO/O_2, C_2H_4/C_2H_6 are useful indicators;
- **Require ppm sensitivity and accuracy;**

C2H4/C2H6 vs coal T

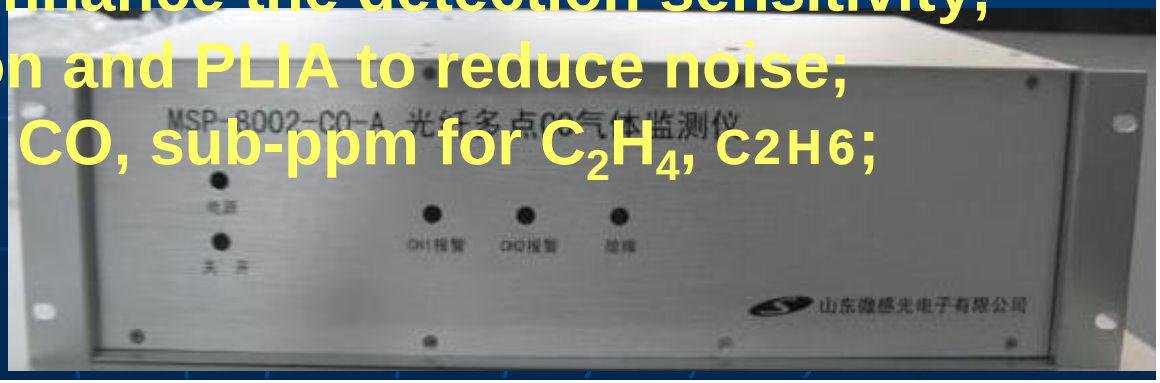


Multi-Gas Trace Detection System

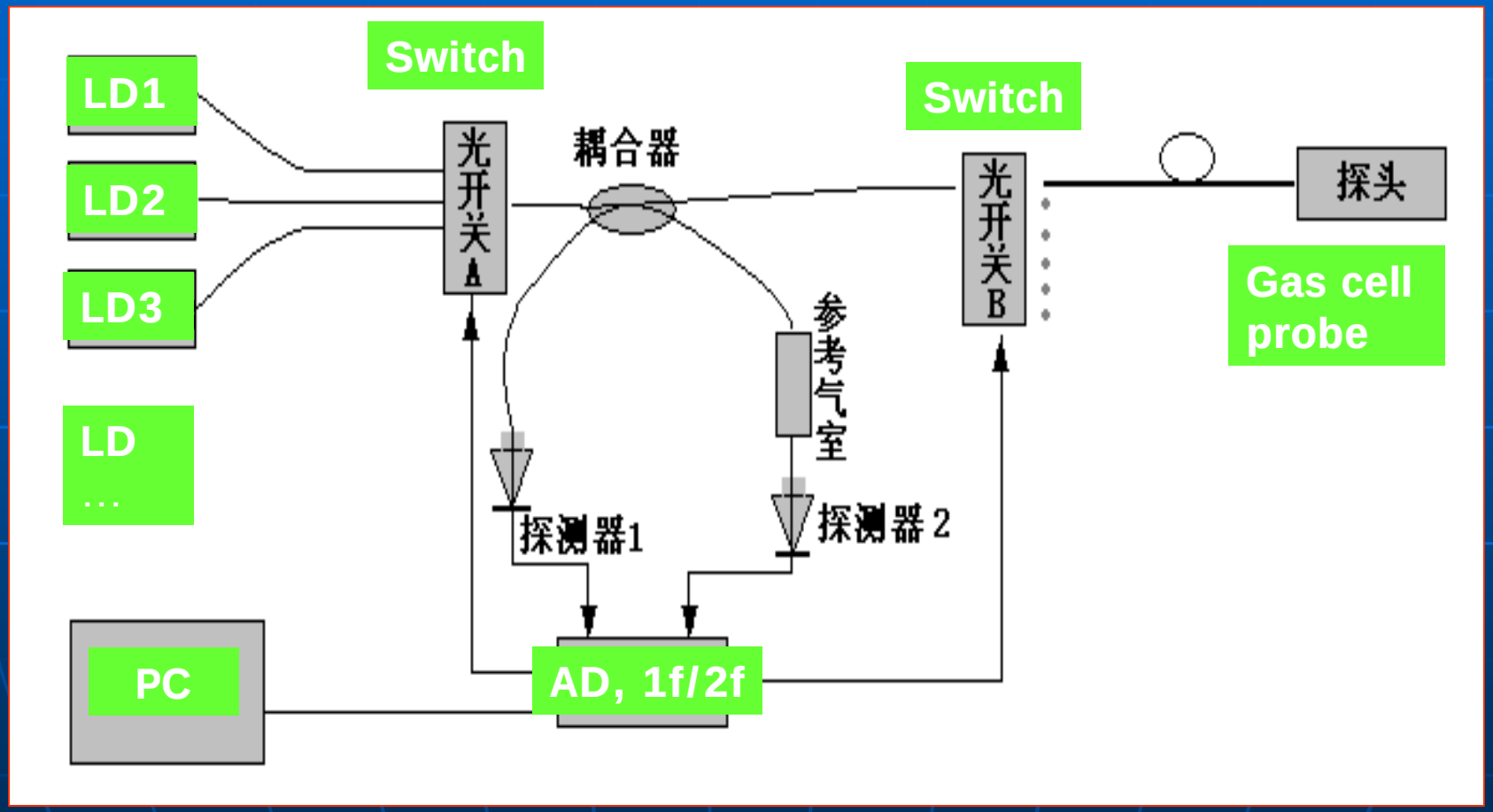




- Multiple reflection to enhance the detection sensitivity;
- 2nd harmonic detection and PLIA to reduce noise;
- ~ 1 ppm sensitivity for CO, sub-ppm for C_2H_4, C_2H_6;

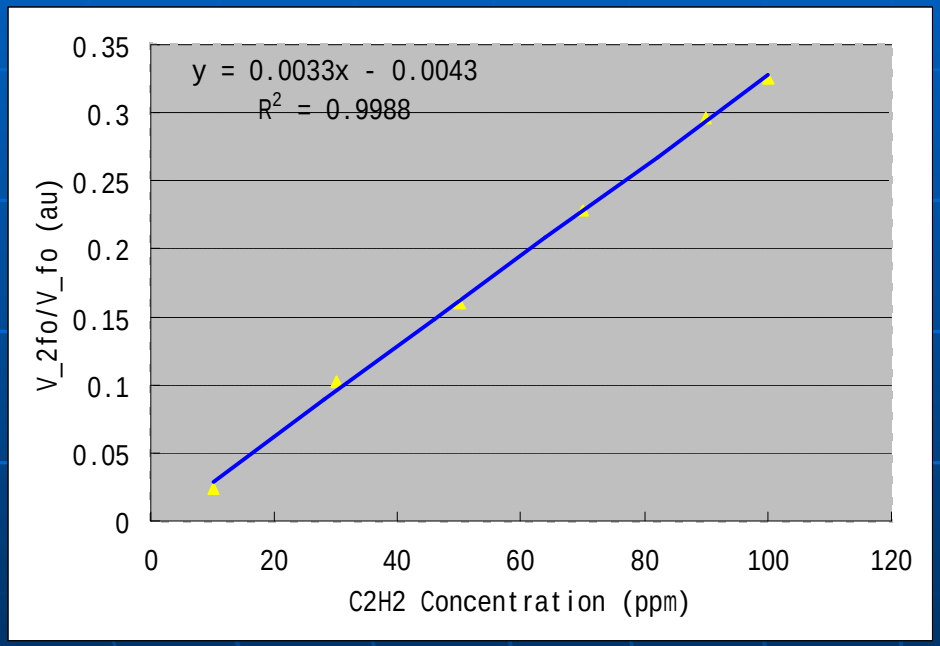


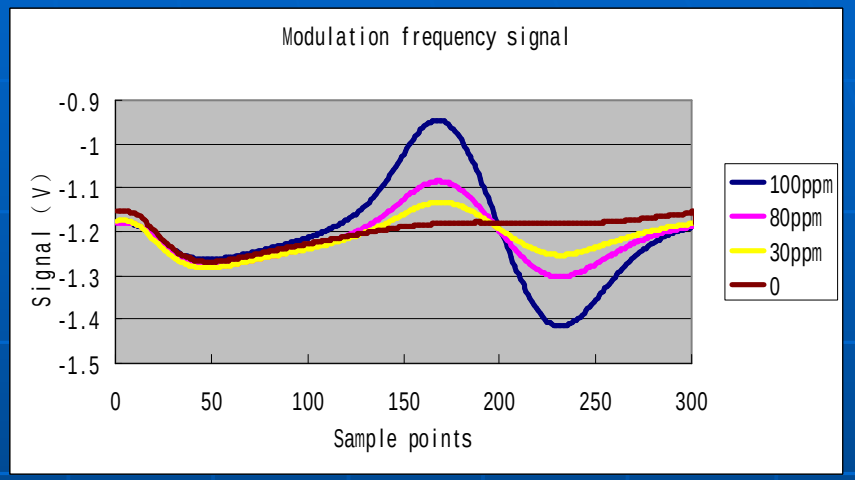
Multiple Gas Trace Detection System

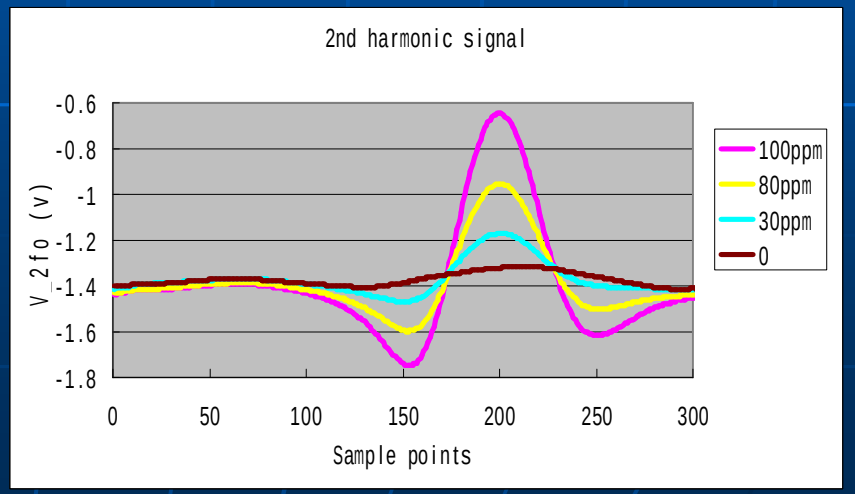


- One gas cell addressed by a bank of laser diodes, which emits at
- absorption band of the gases to be monitored.

Multi-Gas Detection System



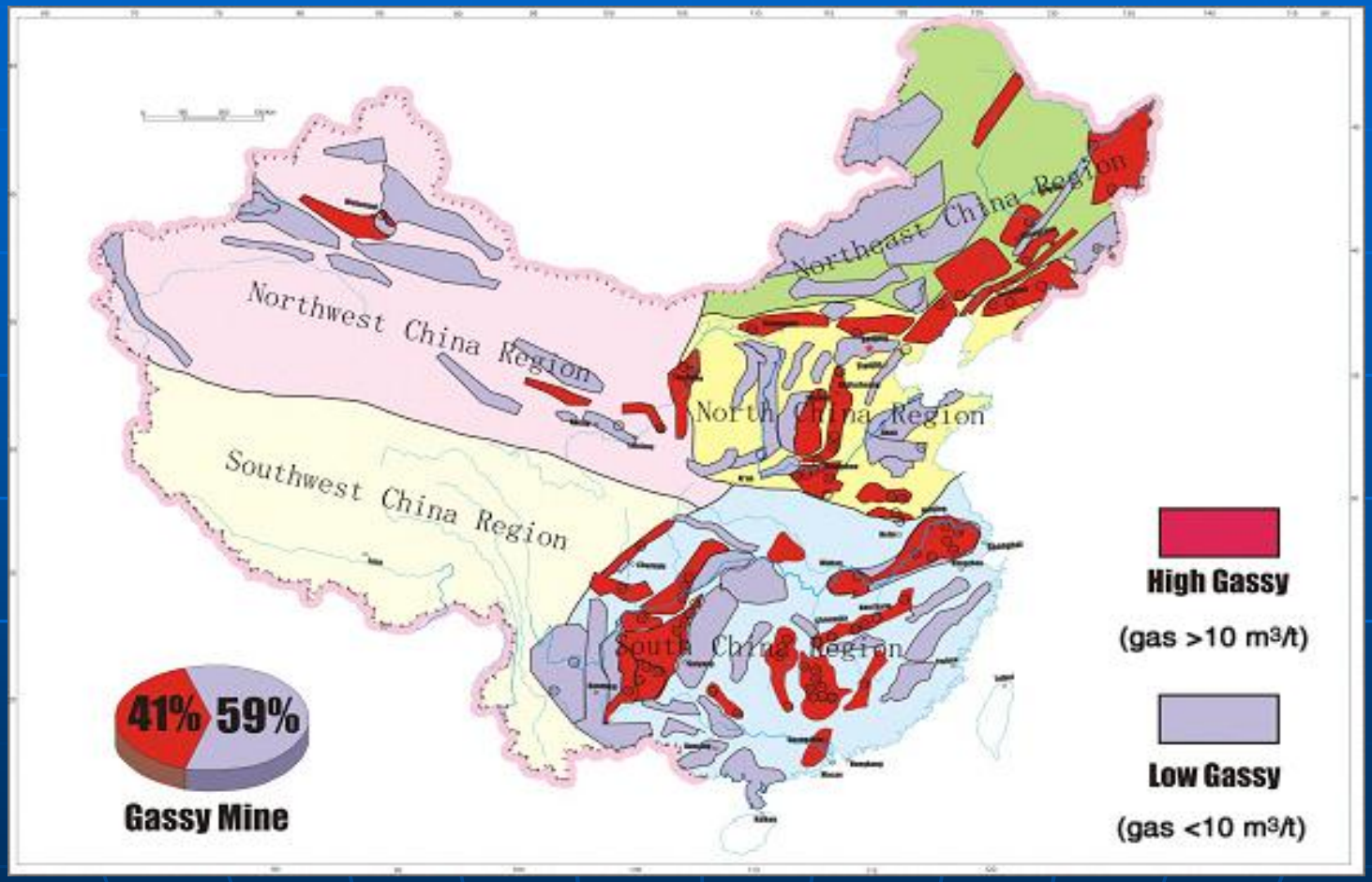




- C_2H_2 concentration vs V2f/V1f.

Illustration how the harmonic detection system work.

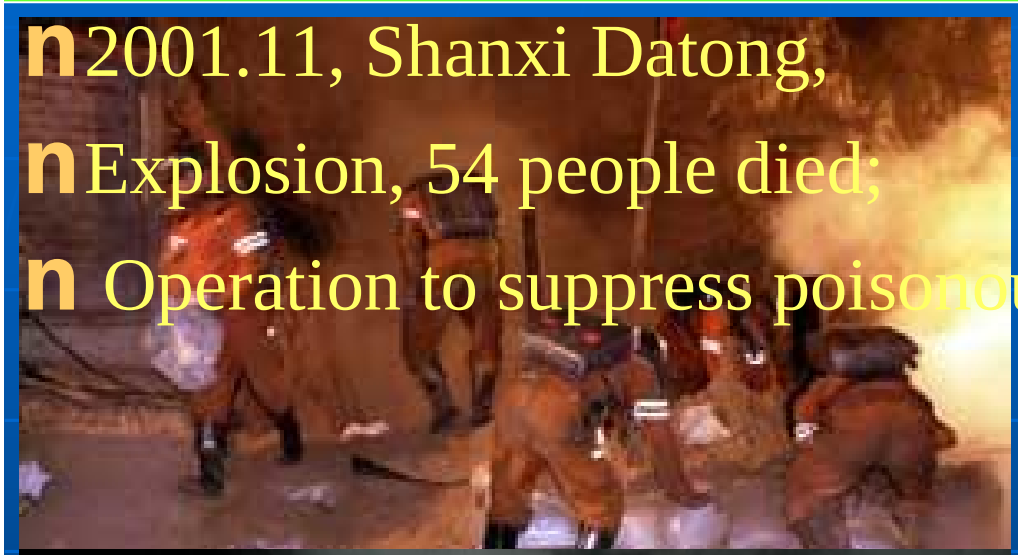
GASSY MINE DISTRIBUTION,CHINA



- Over 50% underground coal mines in the world are gassy;

METHANE EXPLOSION

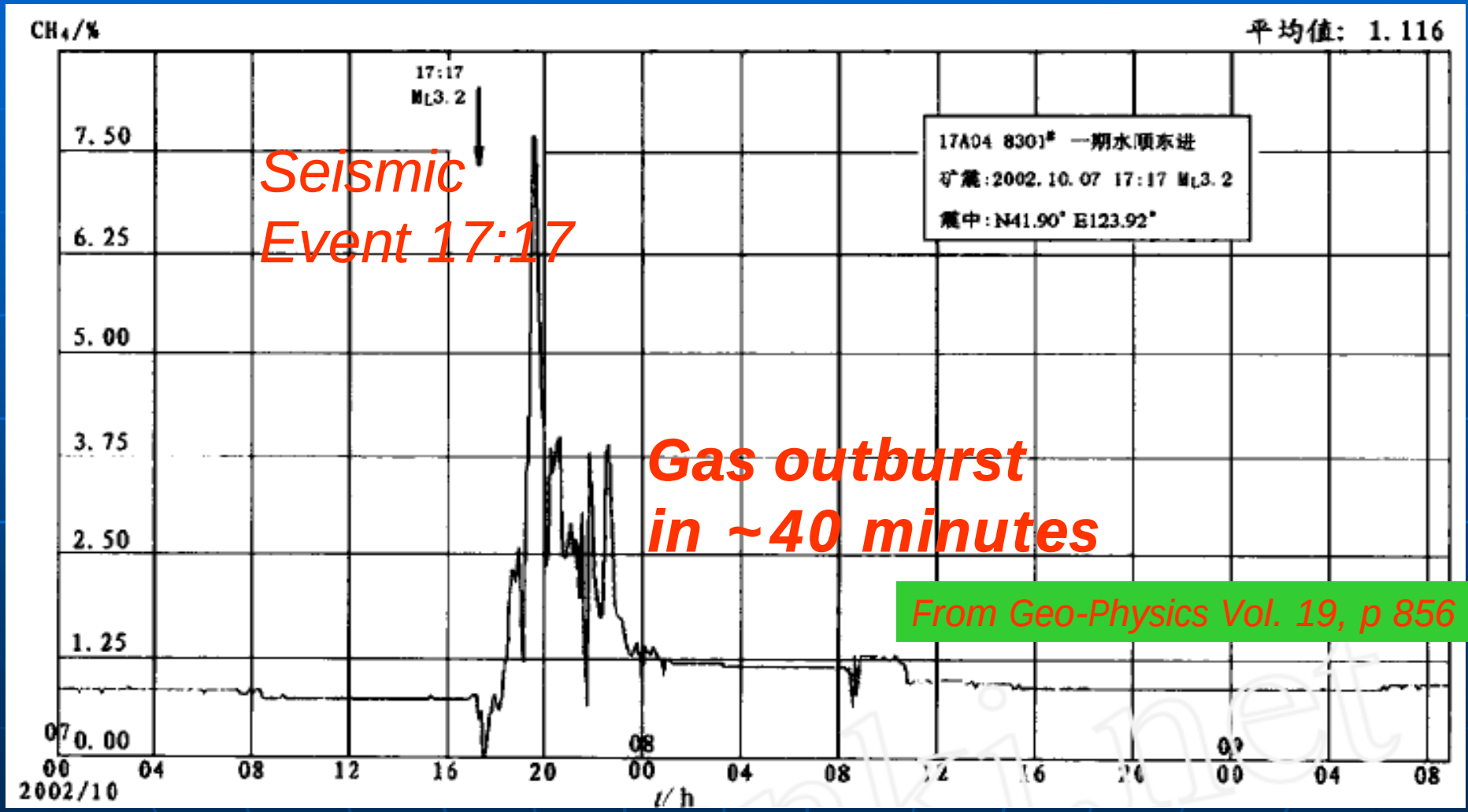
- 2001.11, Shanxi Datong,
- Explosion, 54 people died;
- Operation to suppress poisonous gases emitted.



2006.11 Jiangxi explosion, 7 people died.

2001, Shanxi, explosio 99 people died

Seismic Trigger Methane Gas Burst



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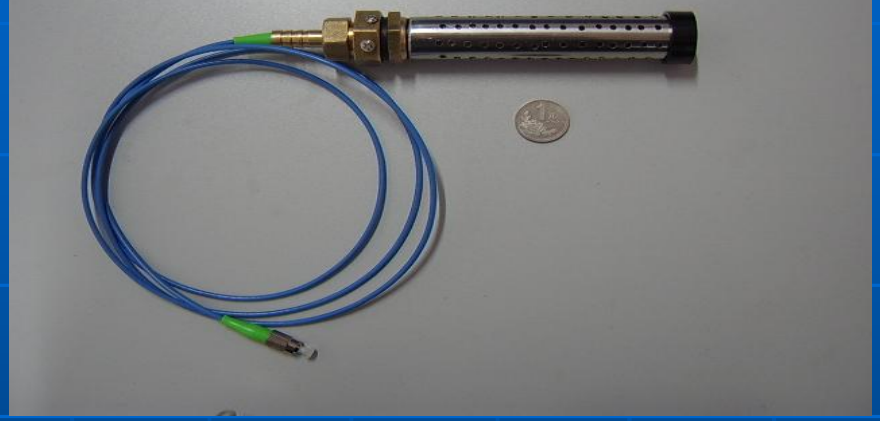
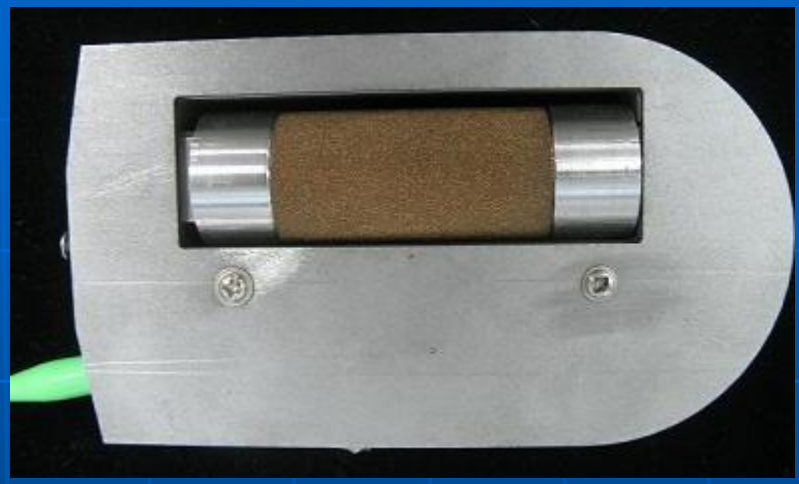
FO Methane Gas Sensor

- Ambient Gas Sensor

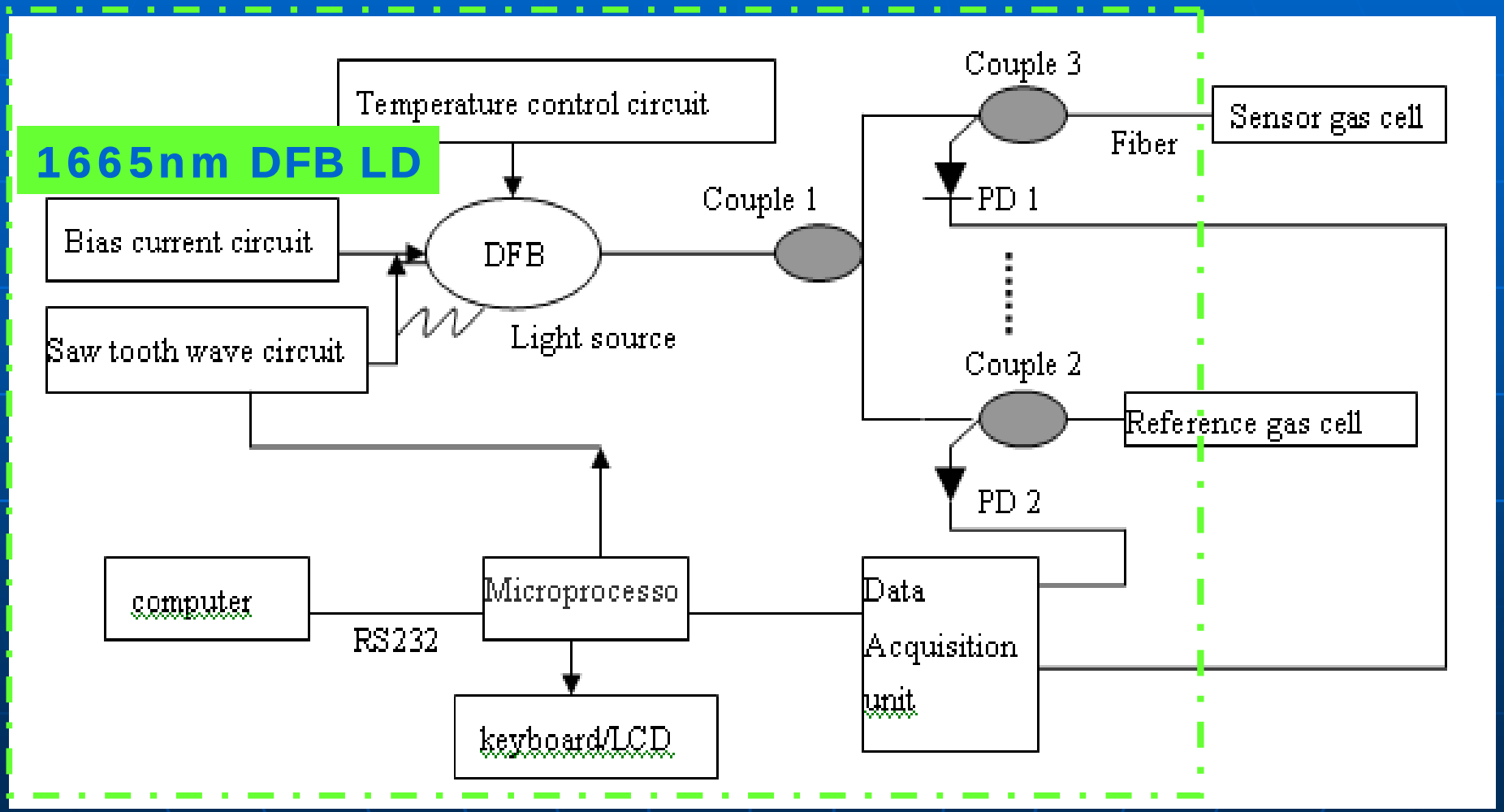




- Pipeline gas sensor

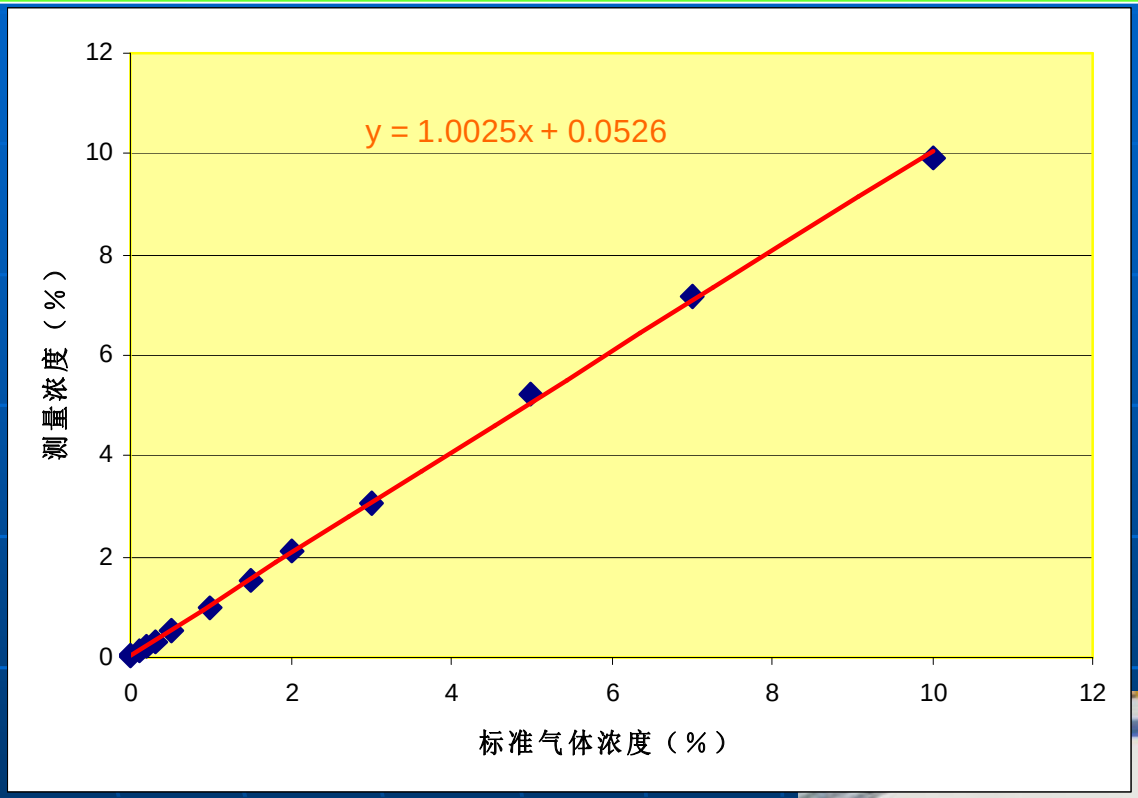
- **Sensor consists of pairs of fiber collimators as gas cell;**
- **Fixing Support and anti-vibration mechanism;**
- **Dust and moisture filters**

FO Methane Detection Principle

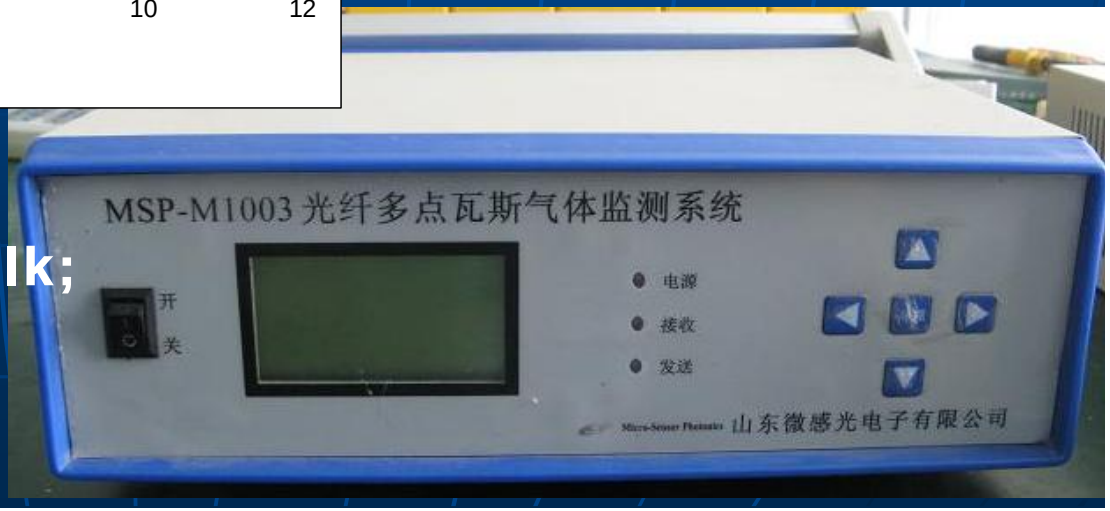


- Laser sweep with internal referencing to achieve field stability.

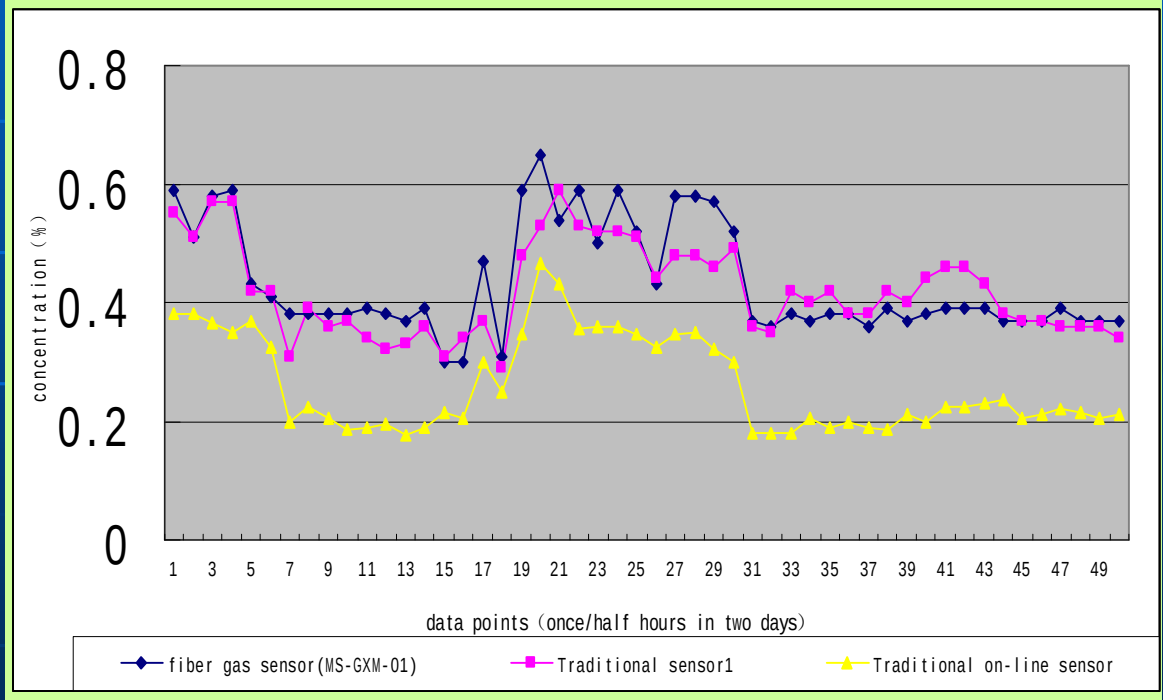
FOS Methane Monitor



- Unique benefits:
- Long calibration cycle;
- Immune to gas cross talk;
- Robust to humidity and ambient T
- Intrinsically safe



Coal Bed Methane Utilization Monitoring - Latest Field Trial



n(Huainan Coal Mine methane power generation plant 2009.09）

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Coal Mine Methane Utilization Monitoring

(Methane extraction power generation plant, Fuxin, Liaoning, 07. 200

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Intelligent Mine Safety Platform

- All fiber optic multi-parameter sensor network, comprising 3 sub-systems;
  - Multiplexed FBG sensor array (*d, P, T, e, a, flow, AE*)
  - Laser absorption based gas sensor array (*Ch4, CO, C_2H_4, CO_2, O_2*)
  - *DTS*
- Data fusion system

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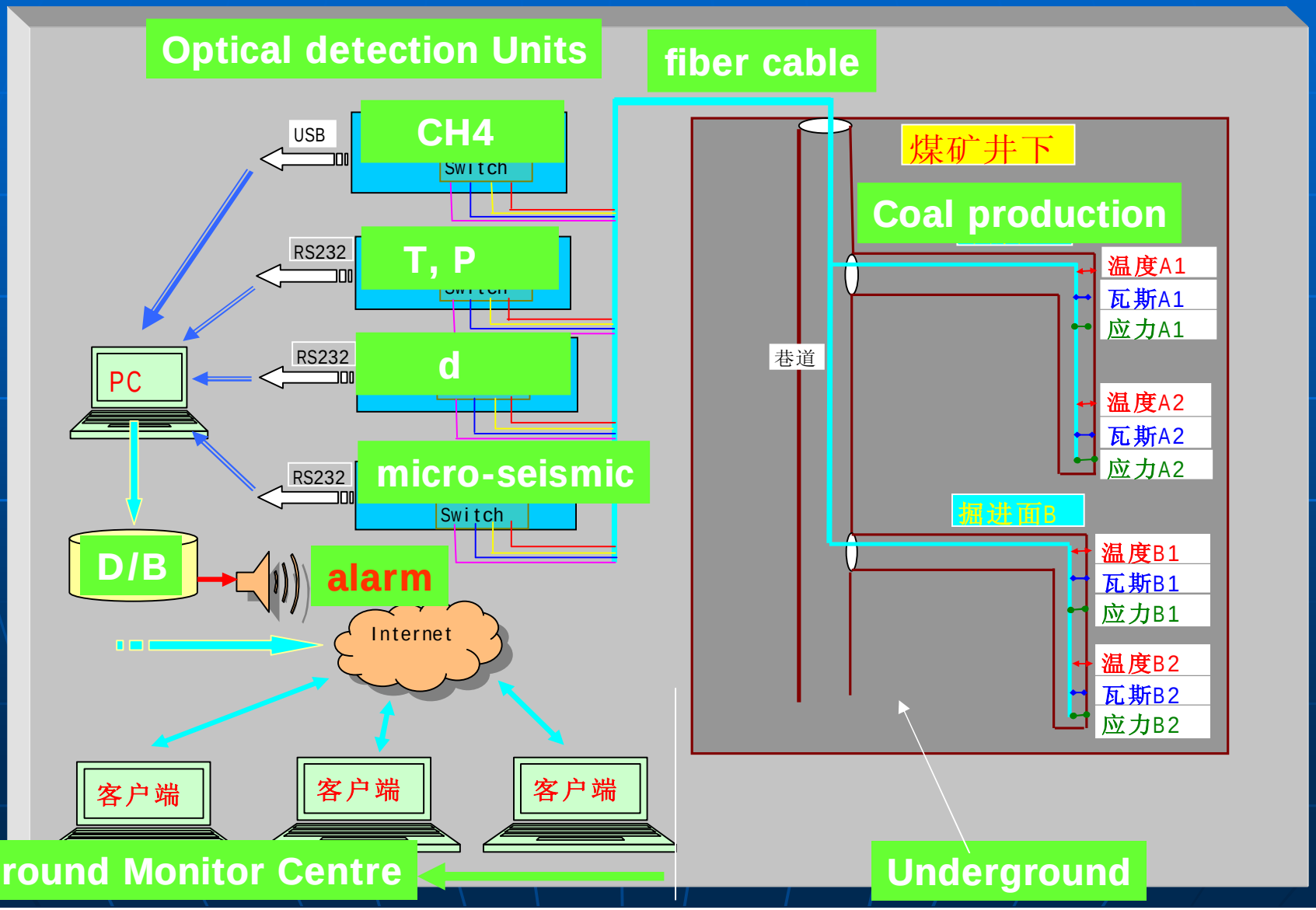
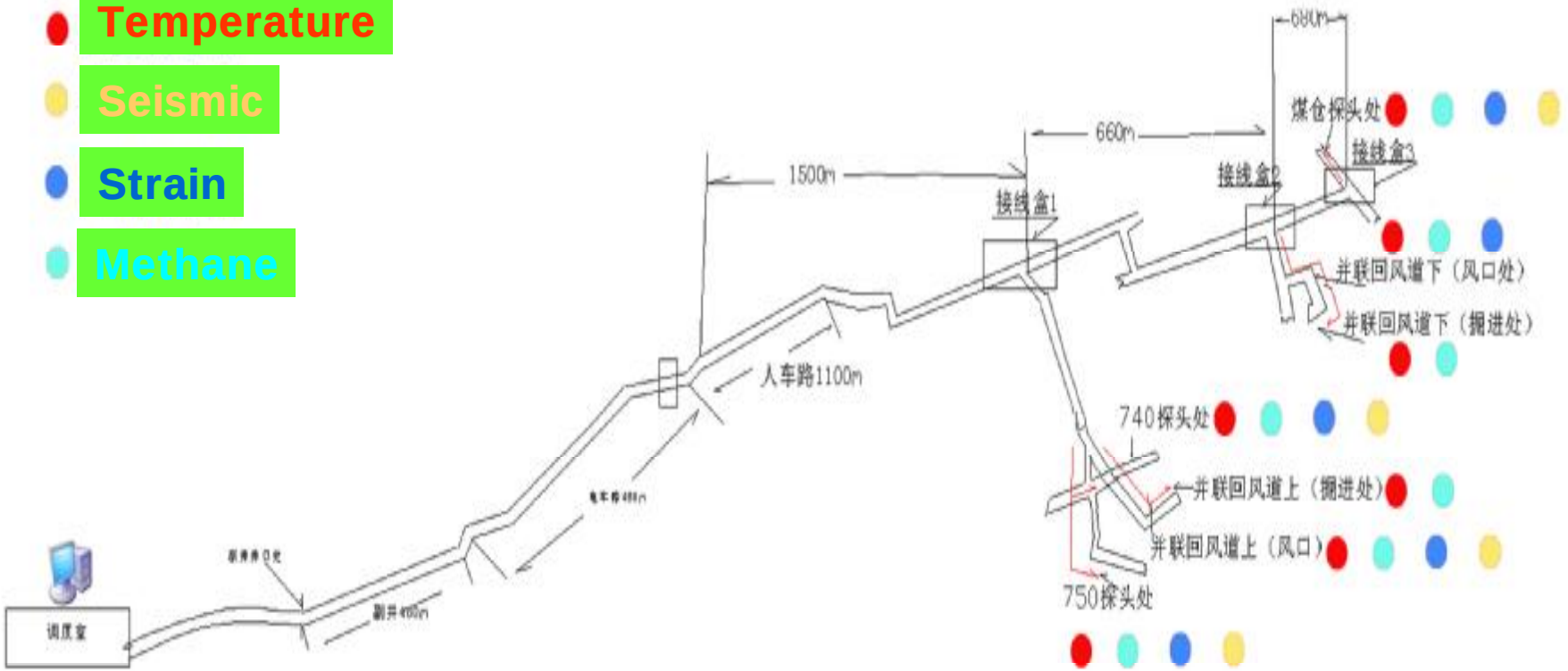
FIELD TRIALS: LINGZI COAL MINE, SHANDONG



Field Trial:
LINGZI COAL MINE, SHANDONG

- **Temperature**
- **Seismic**
- **Strain**
- **Methane**



The first trial in 2007

FIELD INSTALLATION

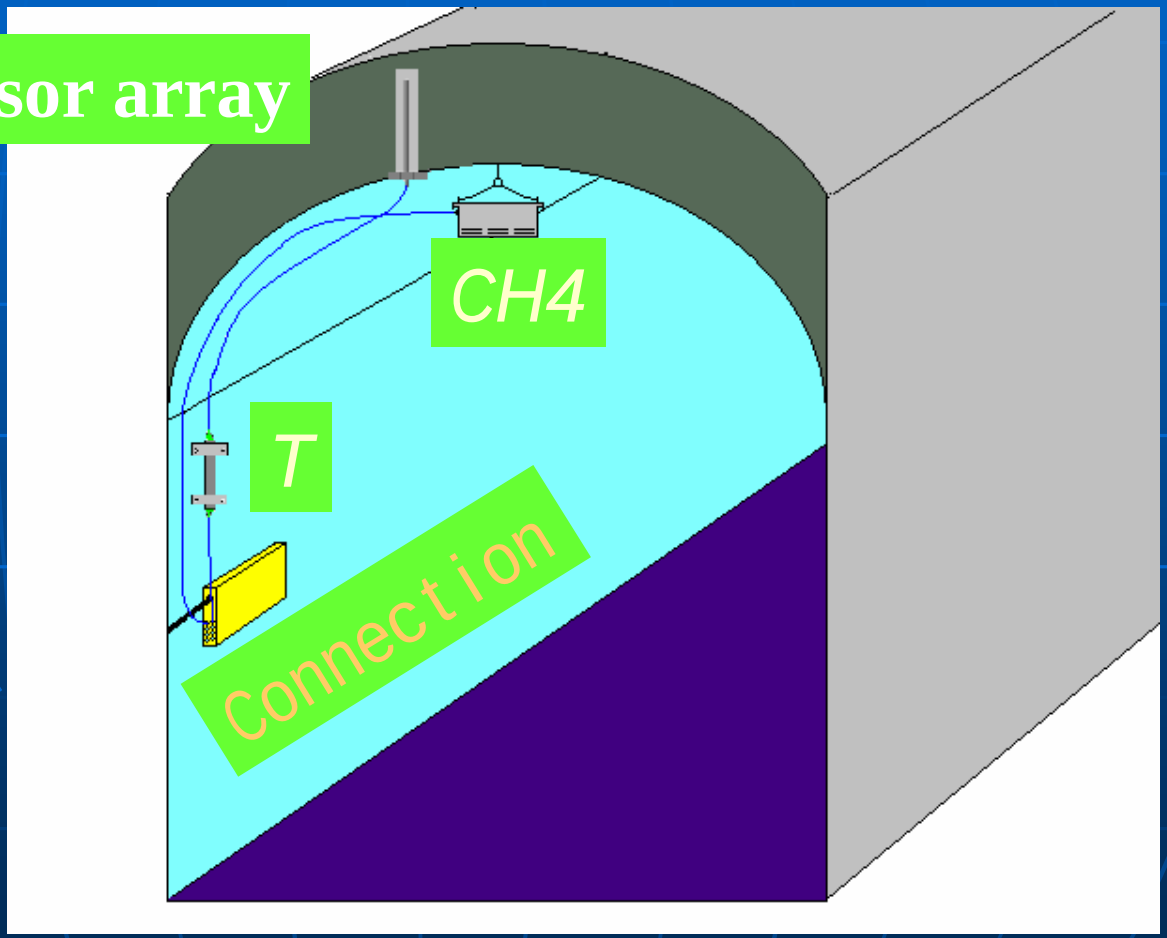
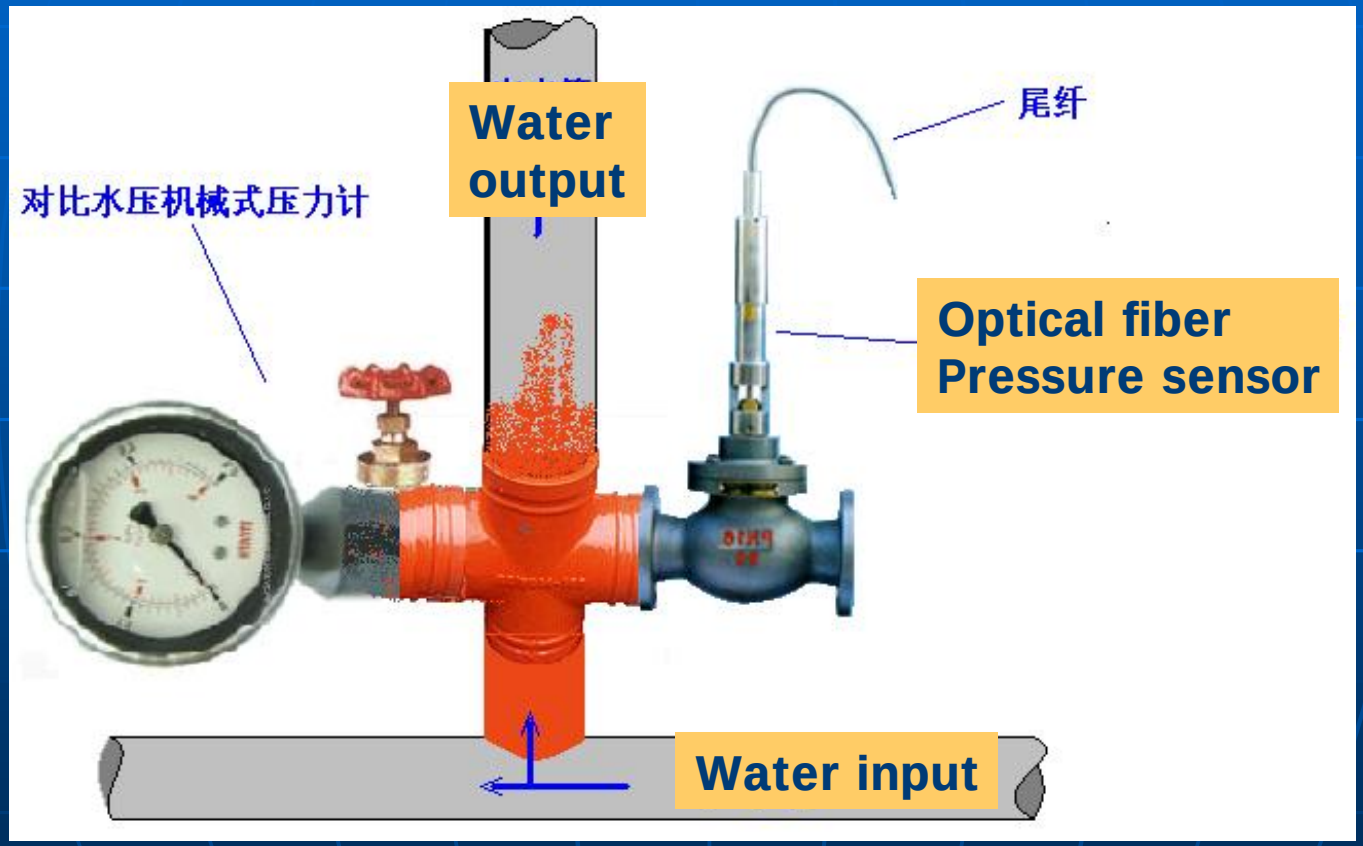


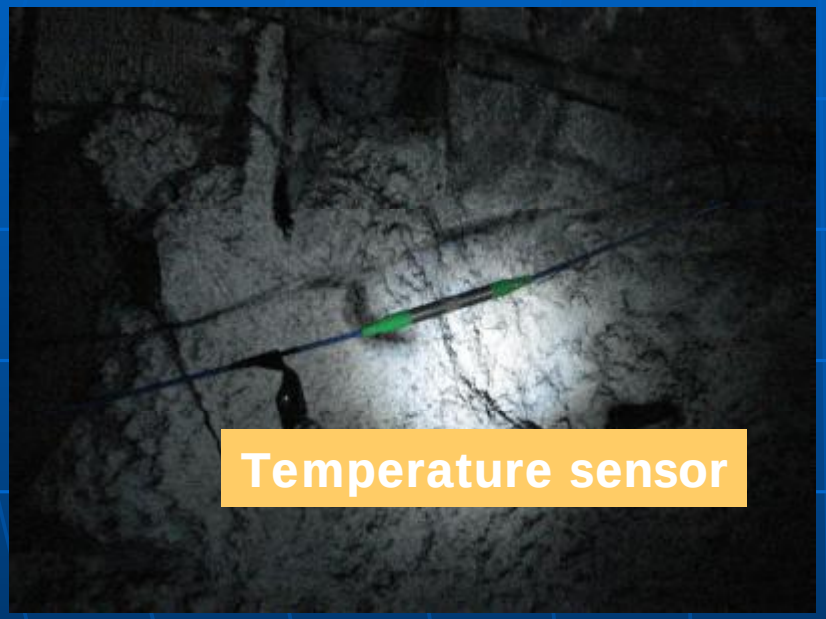
Illustration of Fiber Optic Sensor Installation in the Mine.

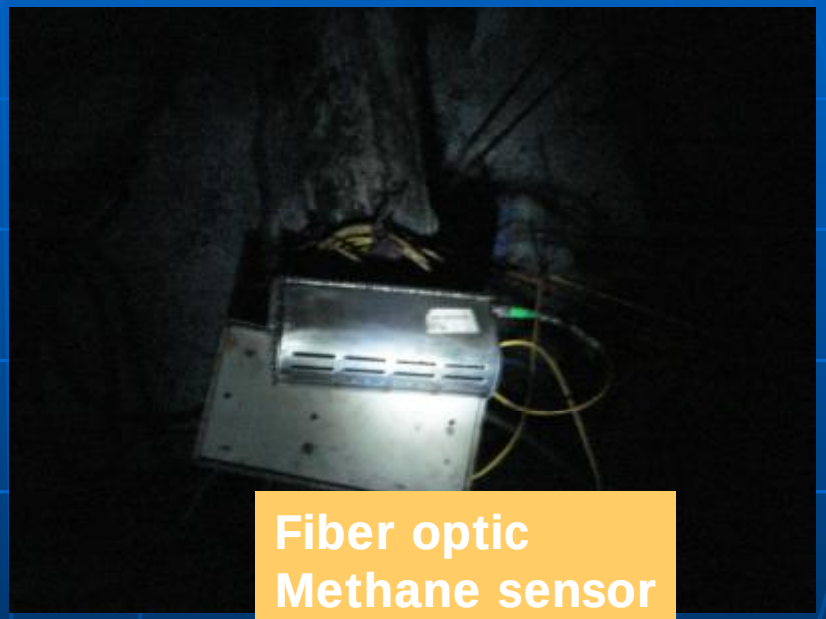
FIELD TRIALS: LINGZI COAL MINE, SHANDONG



- Illustration of water pressure measurement using fiber optic pressure sensors.

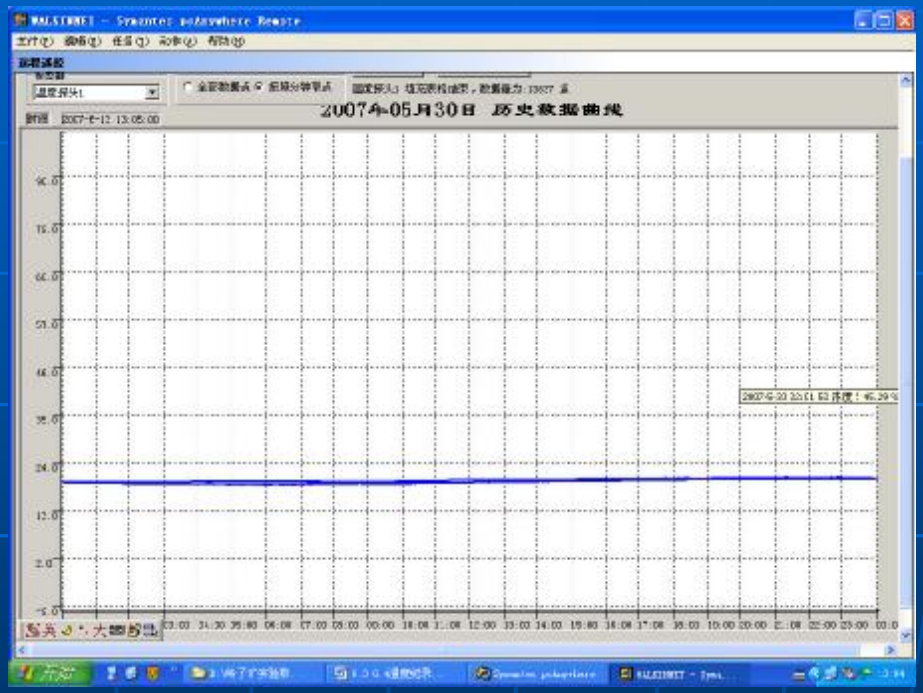
FIELD TRIALS: LINGZI COAL MINE, SHANDONG





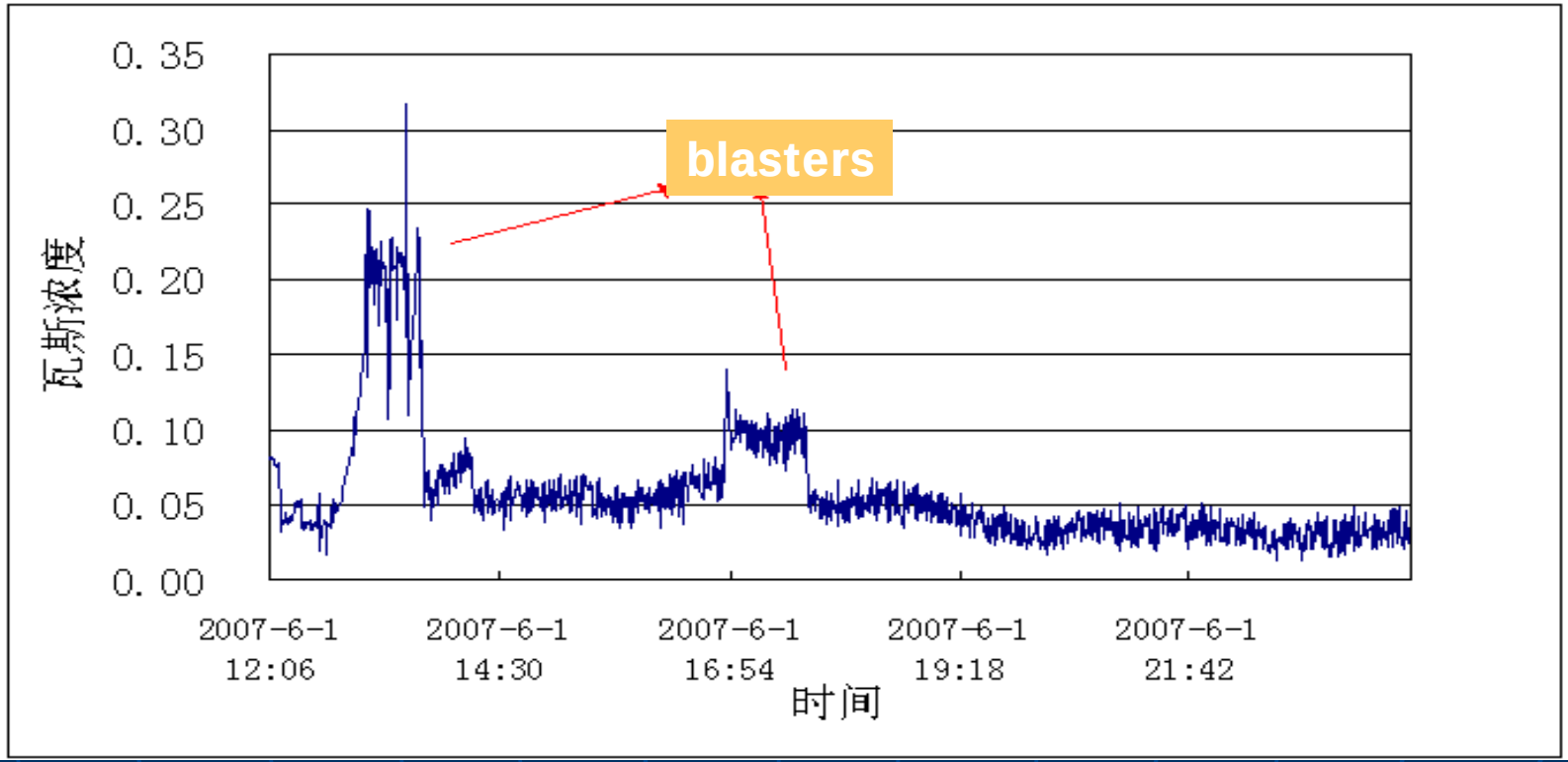
- **Fiber Optic temperature sensors and methane sensors installed in underground coal mine.**

FIELD TRIALS: LINGZI COAL MINE, SHANDONG



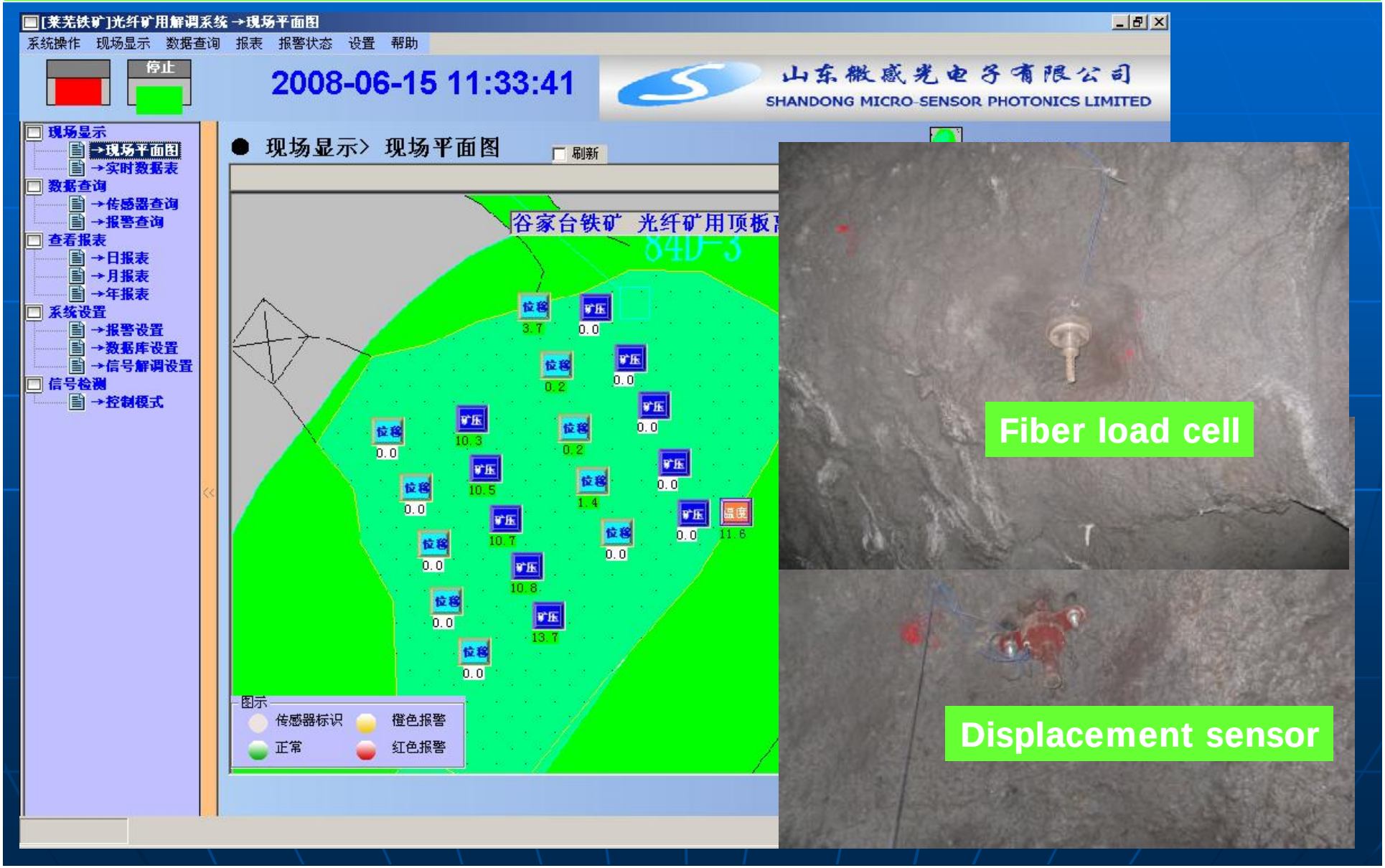
- **Underground temperature is recorded at approximately 22 degree C, accurate within +/-0.5 degree.**

FIELD TRIALS: LINGZI COAL MINE, SHANDONG

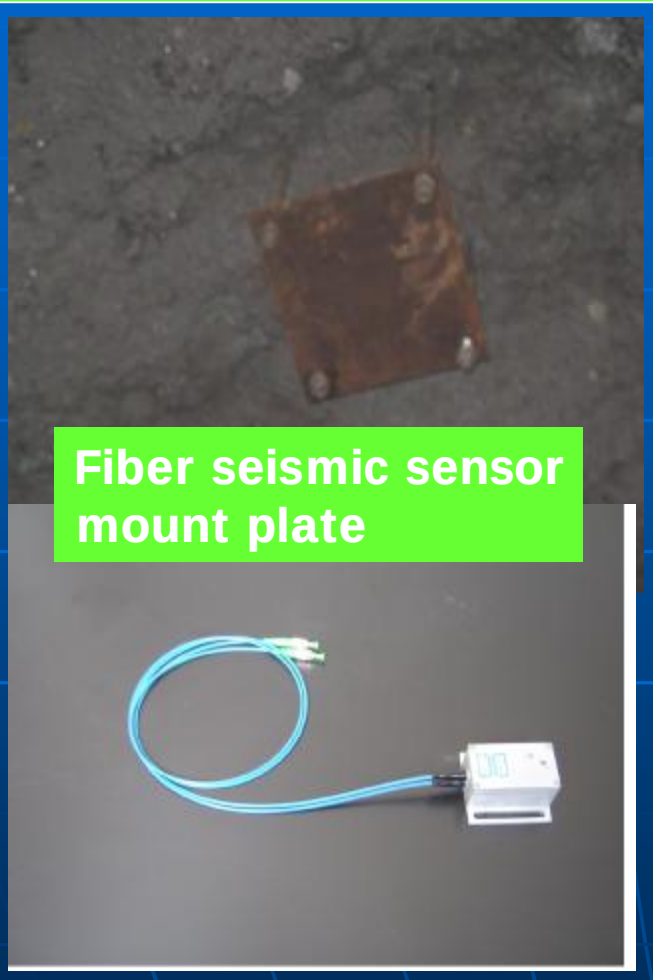


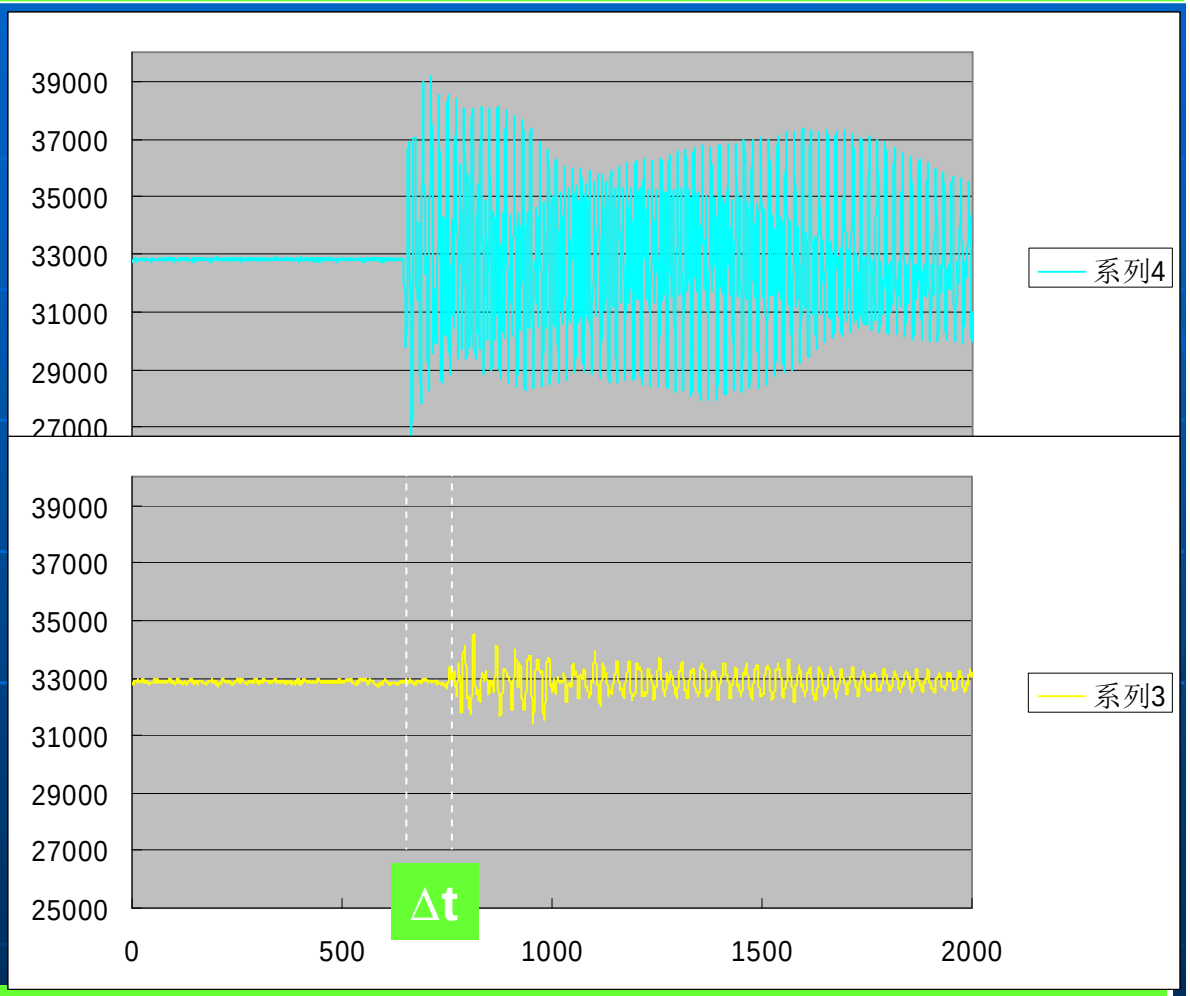
- **Record of methane gas concentration change with time (increase of concentration can be observed after blaster events which agrees with the conventional sensor data).**

Laiwu Iron Ore Mine Roof Monitoring



FIELD TRIALS:Laiwu Iron Ore Mine

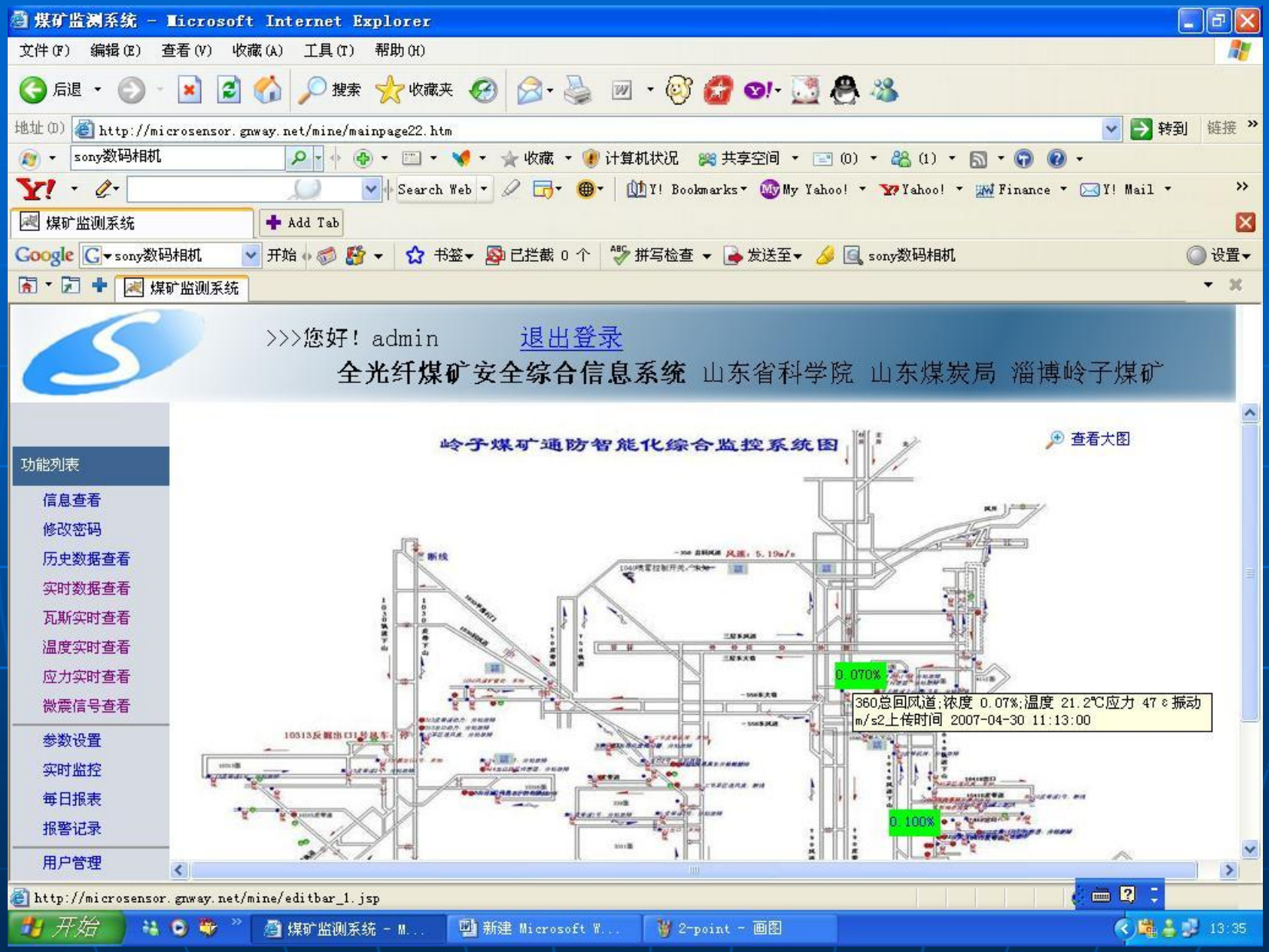




- Recorded mining blaster signals by two FO seismic sensors located 170 m apart. The time delay is apparent which can be used for seismic source location.

FIELD TRIALS: Internet Access

- The FOS mining safety information system is for on-line remote access via internet.



Internet access

Tailings Dam Condition Monitoring

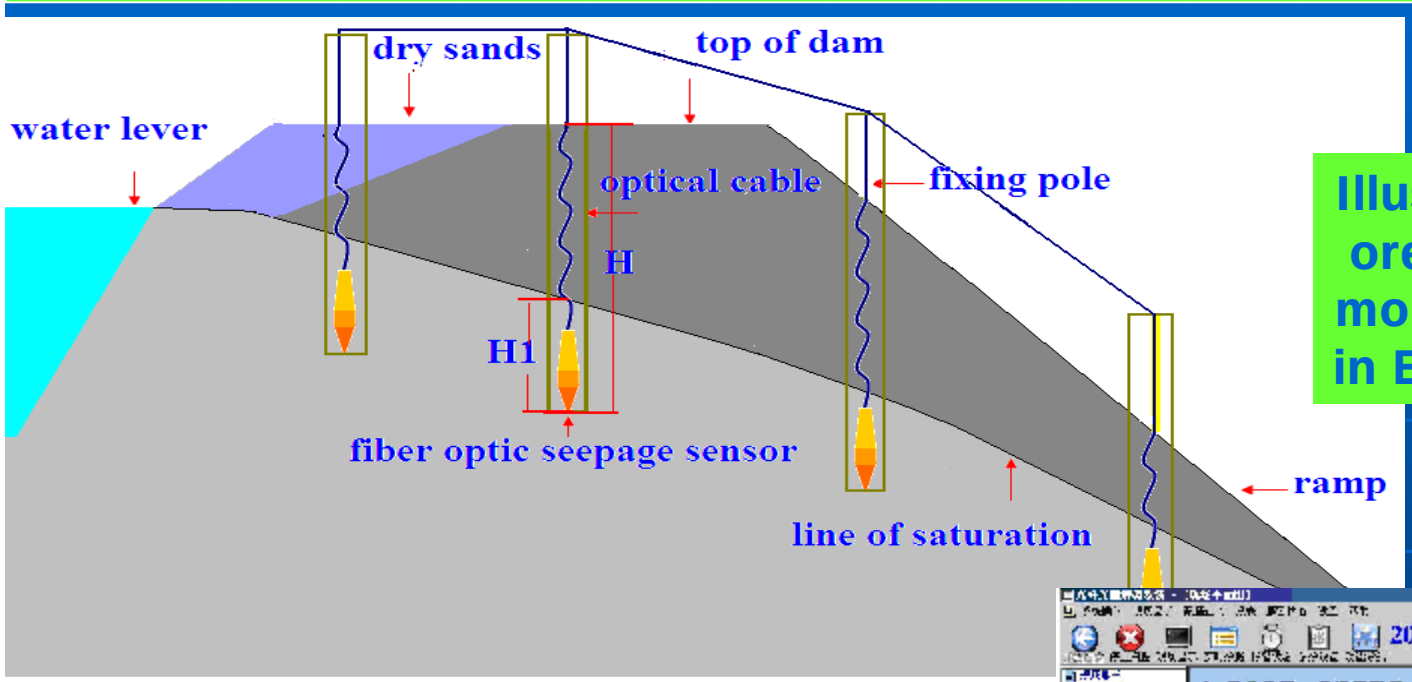


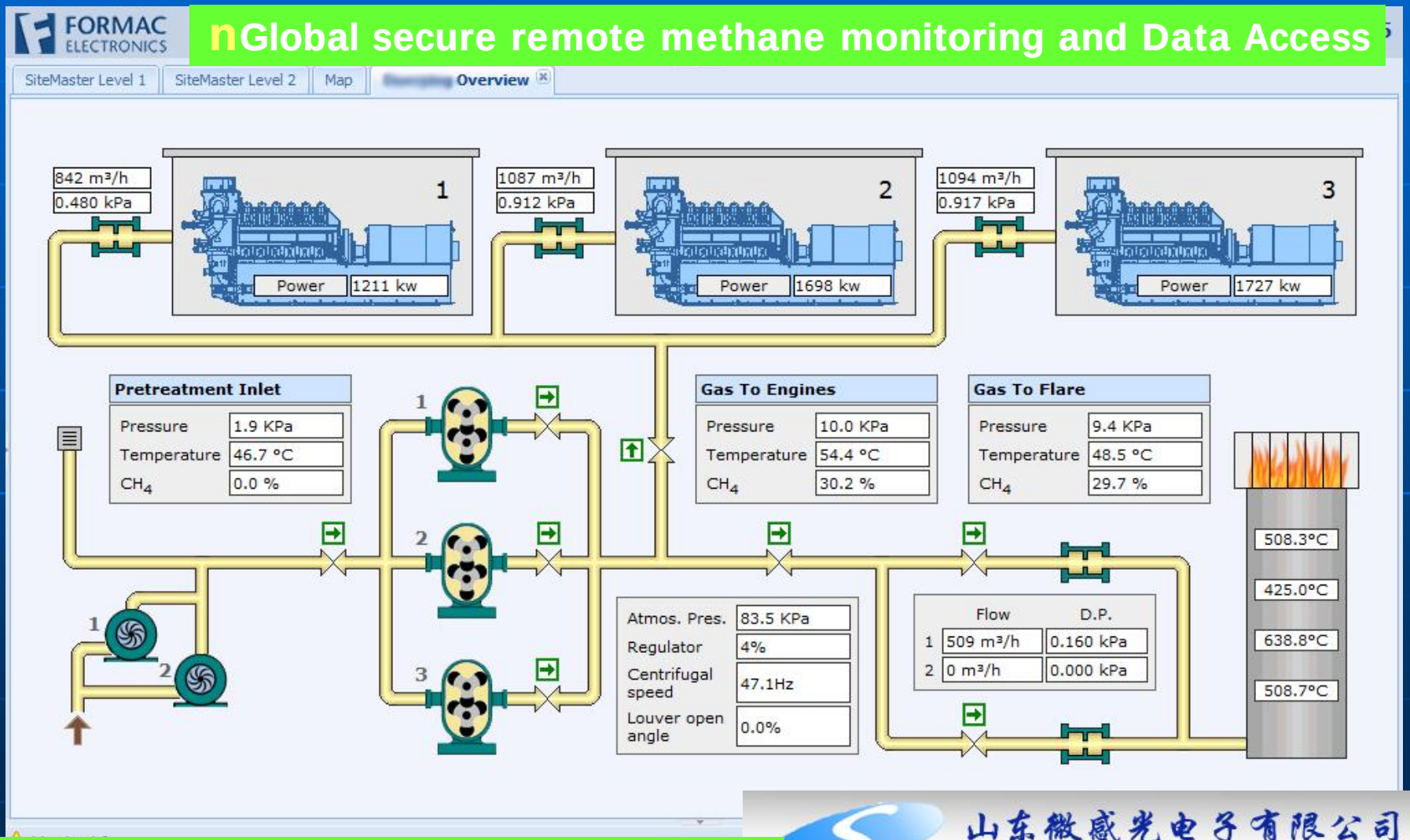
Illustration of an iron ore mine tailings dam monitoring system in Beijing, 06.2008.

- Mineral mine hazards mainly concerned
- with underground roof and ground tailing
- dam safety monitoring.
- Fiber optic water level and displacement
- Sensor net work are developed.

Field Trial: Methane Sensor UK Waste Process Power Plant

FORMAC ELECTRONICS

nGlobal secure remote methane monitoring and Data Access

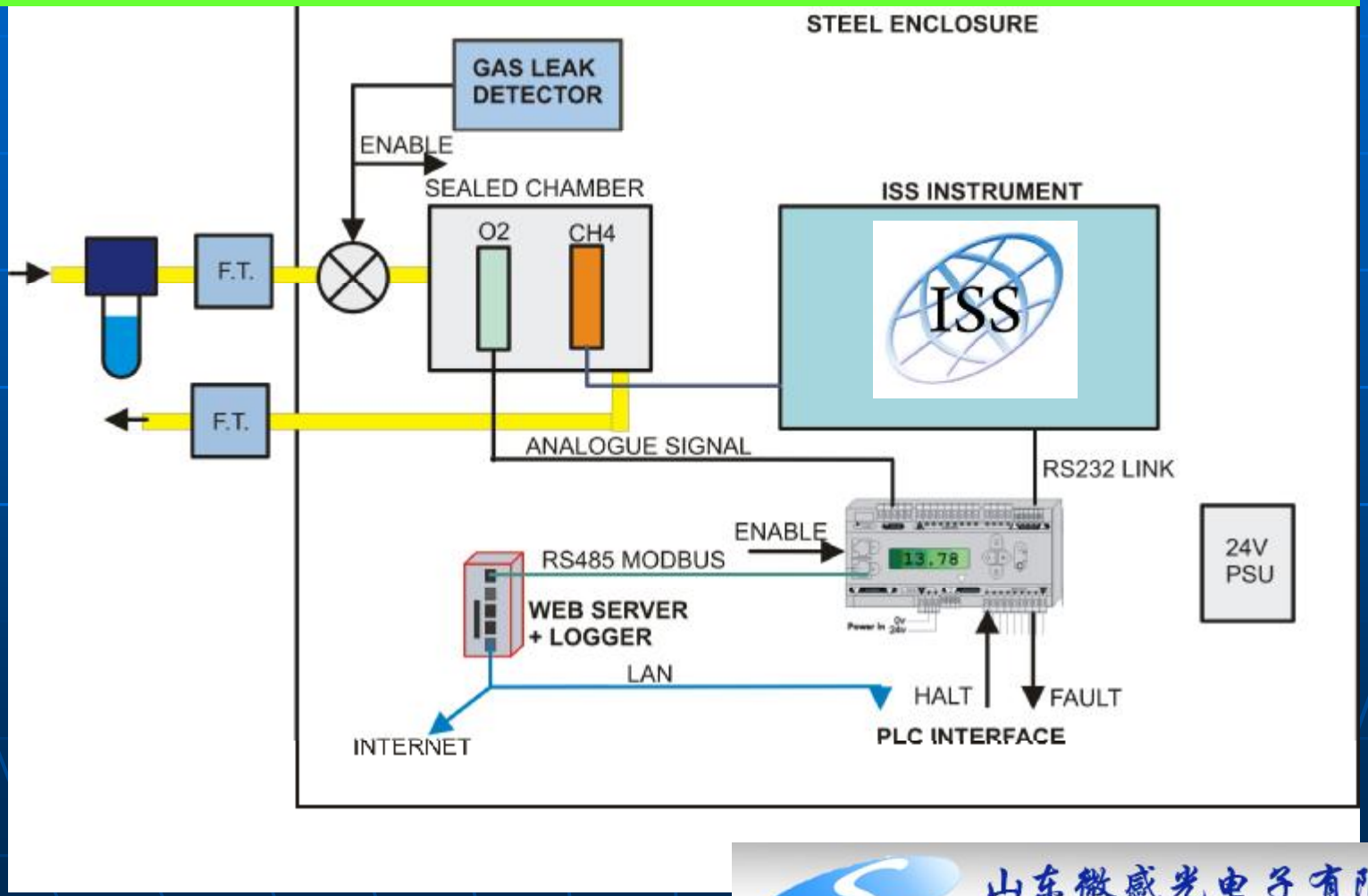


nOn-going field trail min the UK 09.2009.

山东微感光电子有限公司
SHANDONG MICRO-SENSOR PHOTONIC LIMITED

Field Trial: Methane Sensor UK Waste Process Power Plant

- Global secure remote methane monitoring and Data Access



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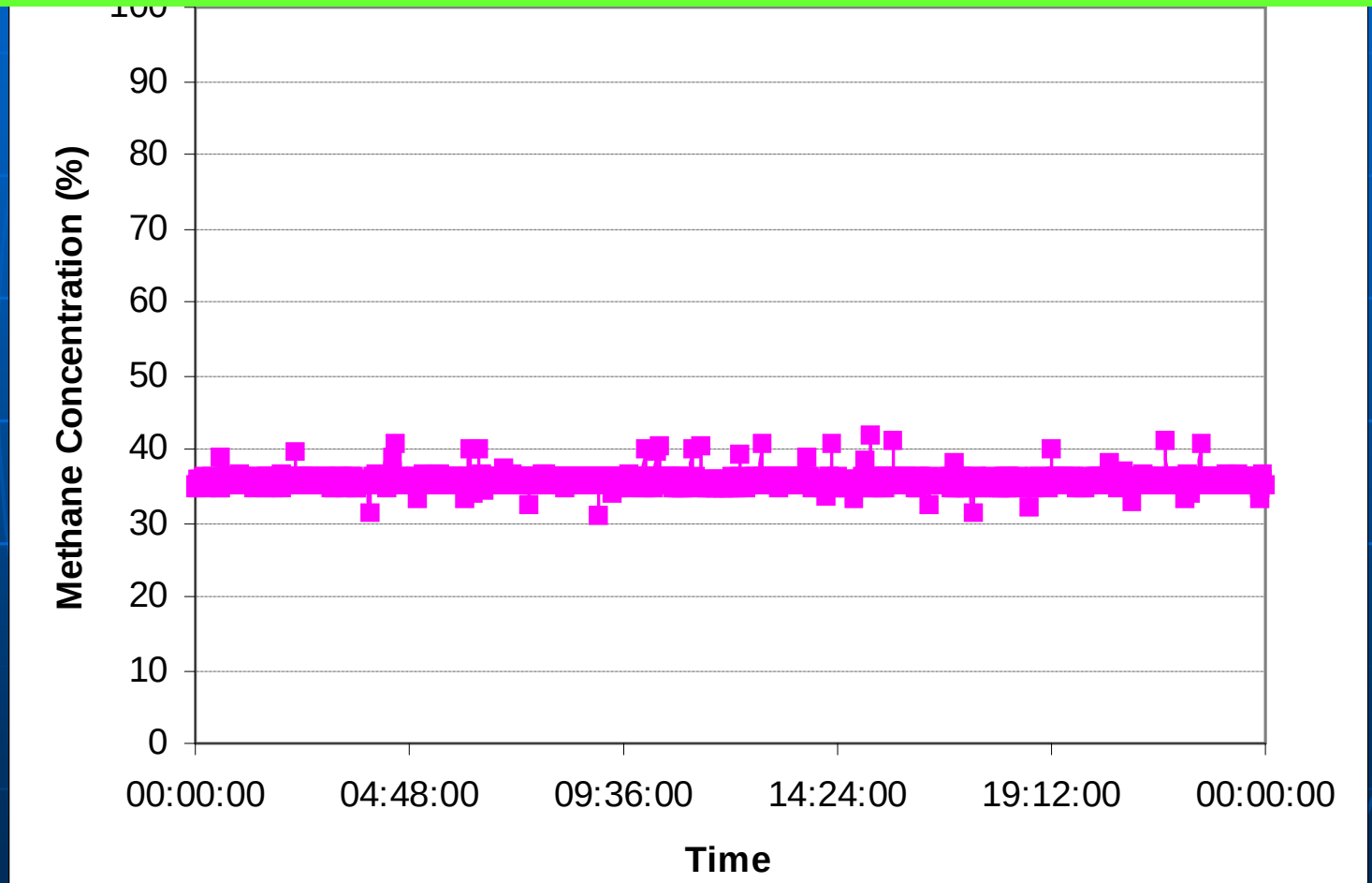

- On-going field trail min the UK 09.2009.

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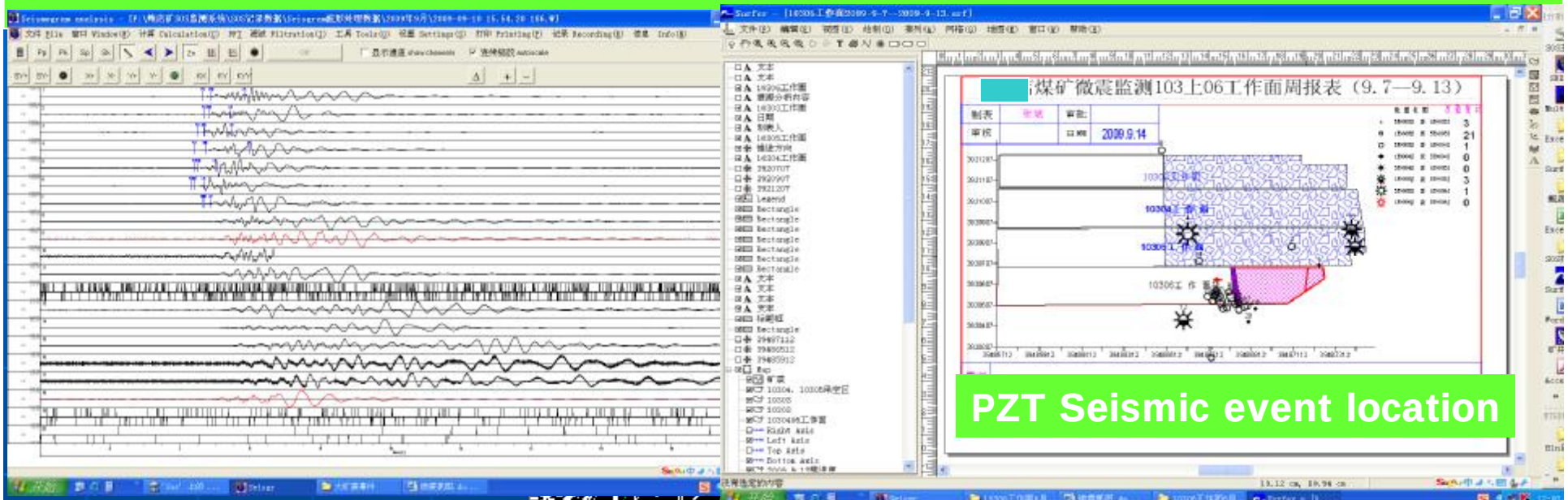
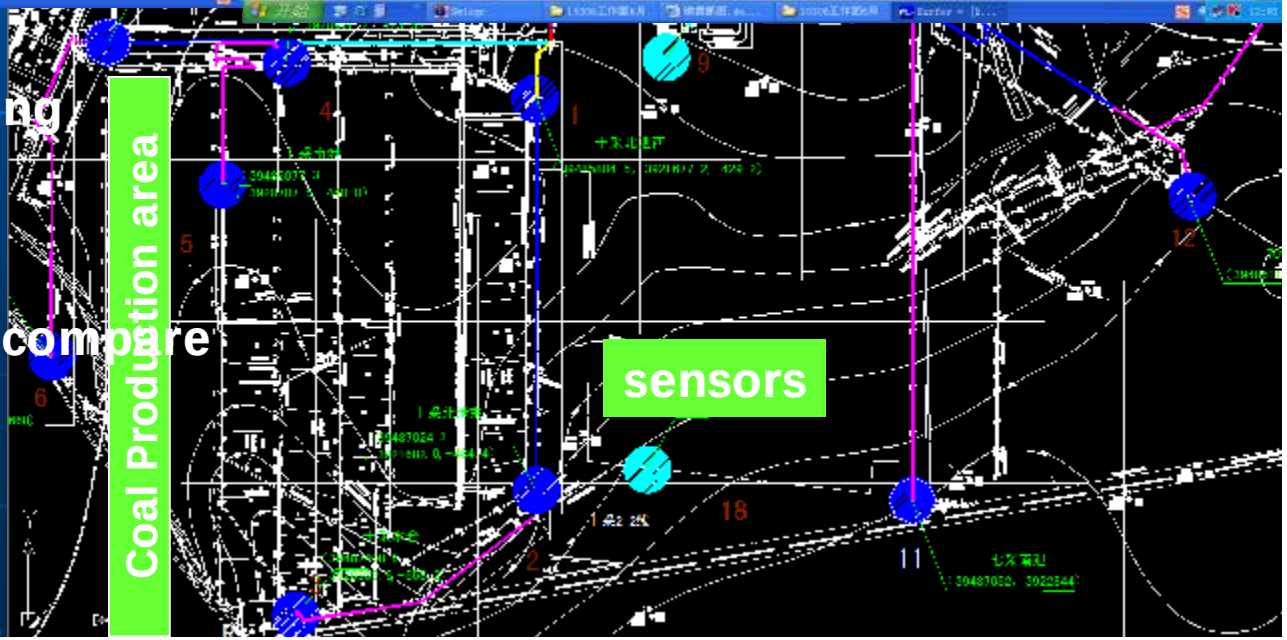
On Going Work – Comparative Study With PZT Seismic Sensor Network



- Real PZT Seismic recording
- And location.

- To put OFS in the same
- Location as the PZT and compare



Challenges and Opportunities

- OFS can play a key role in enhancing even revolutionizing coal mine and mineral mine safety;
- Fiber optic FBG sensors, DTS, laser spectroscopic gas sensors, seismic sensors have been successfully demonstrated to become a comprehensive mining safety and hazard management info system …
- The diversified, on-line, multi-location information provides a foundation for more accurate and timely mining hazard early warning and control;

Challenges and Opportunities

- OFS intrinsically safe in explosive environment, is irreplaceable for the development of modern intrinsic safe and digital mining.
- OFS also play key role in environmental system such as coal bed methane utilization…
- Many opportunities and challenges for OFS application in the mines, e.g. sensitive fiber microphone array for emergency rescue communication; dust monitoring; cable and sensor protection, etc.

Acknowledgement

- Thanks to our colleagues at Laser Inst, Shandong Academy of Science and Shandong Micro-Sensor Photonics Ltd;
- Colleagues in coal and mineral mines for supporting the trials.
- Grants from National, provincial and the Shandong Academy of Science are acknowledged

Thank you for your attention !

- ***Welcome your collaboration !***
- ***Together, OFS can save lives and the planet !***

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