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MEASUREMENT OF ULTRAFAST CHANGING TEMPERATURE USING OPTIC FIBER NON-CONTACT METHOD.

Musurmonov Madumar
YEOJU Technical Institute in Tashkent

Abstract

Due to their unique properties, optical fibers are used in wide branches, including medicine, the motor industry, aircraft, mechanical engineering, telecommunication, Internet networks and etc. Optical fibers differ from traditional cables with their high bandwidth, immunity to electromagnetic influence. The application of optical fiber not only for the transfer of information but also for sensor technologies is an important problem from a technical point of view. The problem becomes more interesting in such applications where traditional sensors are not able to detect transient processes. Among these problems, the fast change of temperature of an object in the industry can be solved using optical fibers.

By means of the present article, I propose a possibility of application of optical fibers in industry, in particular, for fast and continuous measurement of temperature. The properties of present optical fibers and suggestions of using them in high-temperature environment are discussed.

Keywords: optic fiber, pyrometer, radiation, temperature, welding, sensor, infratherm.

JUDA TEZ O`ZGARUVCHAN TEMPERATURANI OPTIK NUR TOLA ORQALI MASOFADAN TURIB O`LCHASH.

Musurmonov Madumar
Toshkent shahridagi Yodju Texnika Instituti

Annotatsiya

Hozirgi kunda, o'zining noyob xususiyatlaridan kelib chiqqan holda optik tolalar tibbiyot, avtomobilsozlik, samolyotsozlik, mashinasozlik, telekommunikatsiya, Internet tarmoqlari va boshqalarni o'z ichiga olgan keng sohalarda qo'llaniladi. Optik tolalar an'anaviy kabellardan yuqori o'tkazish qobiliyati, elektromagnit ta'sirga chidamliligi bilan ajralib turadi. Optik tolani nafaqat axborot uzatish, balki sensor texnologiyalari uchun ham qo'llash texnik nuqtai nazardan muhim narsa hisoblanadi. An'anaviy sensorlar o`zgaruvchan jarayonlarni tahlil qlolmaydigan holatlarda optik tolalar juda dolzarb yechim hisoblanadi. Ushbu muammolar orasida sanoatdagi ob'ekt haroratining tez o'zgarishini optik tolalar yordamida hal qilish mumkin.

Ushbu maqola orqali men optik tolalarni sanoatda, xususan, haroratni tez va uzluksiz o'lchash uchun qo'llash imkoniyatini korib chiqaman. Hozirgi optik tolalarning xususiyatlari va ularni yuqori haroratli muhitda qo'llash bo'yicha takliflar beraman.

Kalit sozlar: optik tola, pirometr, radiatsiya, harorat, payvandlash, sensor, infraterm.

ИЗМЕРЕНИЕ СВЕРХБЫСТРОГО ИЗМЕНЕНИЯ ТЕМПЕРАТУРЫ С ИСПОЛЬЗОВАНИЕМ ОПТИЧЕСКОГО ВОЛОКНА БЕСКОНТАКТНЫМ МЕТОДОМ.

Мусурмонов Мадумар
Технический институт ЁДЖУ в городе Ташкент

Аннотация

Благодаря своим уникальным свойствам оптические волокна находят применение в самых разных отраслях, в том числе в медицине, автомобилестроении, авиации, машиностроении, телекоммуникациях, сетях Интернет и т. д. Оптические волокна отличаются от традиционных кабелей высокой пропускной способностью, невосприимчивостью к электромагнитным воздействиям. Применение оптического волокна не только для передачи информации, но и для сенсорных технологий является важной задачей с

технической точки зрения. Проблема становится более интересной в таких приложениях, где традиционные датчики не способны обнаруживать переходные процессы. Среди этих проблем быстрое изменение температуры объекта в промышленности может быть решено с помощью оптических волокон.

С помощью настоящей статьи я предлагаю возможность применения оптических волокон в промышленности, в частности, для быстрого и непрерывного измерения температуры. Обсуждаются свойства существующих оптических волокон и предложения по их использованию в высокотемпературной среде.

Ключевые слова: оптоволокно, пирометр, излучение, температура, сварка, датчик, инфратерм.

Introduction

Optical fiber technology was considered to be a major driver behind the information technology revolution and the huge progress on global telecommunications that has been witnessed in recent years. Fiber optic telecommunication is now taken without any consideration insight of its wide-ranging application because the best suited singular transmission medium for voice, video, and data signals. Indeed, optical fibers have now penetrated virtually all segments of telecommunication networks - be it trans-oceanic, transcontinental, inter-city, metro, access, campus, or on-premise. Initial R&D (Research and Development) revolution in this field had centered on achieving optical *transparency* in terms of exploitation of the *low-loss* and *low-dispersion* transmission wavelength windows of high-silica optical fibers.

Some industrial techniques deal with a transient process or rapid change of parameters. As an example, fast change of temperature during welding, sintering, and electrical discharging occurs very fast that making thermal control to be complicated. Ultrafast sintering is a strong non-equilibrium process that enables the strong binding of metal-ceramic powders to produce a wide range of advanced composite materials. To accurately control the microstructure it is imperative to measure the temperature of the compact. Contact-based temperature measurement methods, despite their intrinsic advantages, are unsatisfactory here because they may interact with the high-intensity electromagnetic fields, thereby resulting in erroneous measurements. An attractive alternate method is the non-contact infrared temperature measurement. It is based on the measurement of the infrared intensity emitted by the sintering body.

I propose a large core silica optical fiber to directly transfer infrared emission from the compact to an external infrared pyrometer. Optical fibers are inserted in a drilled hole through the insulating die. One end is connected to a pyrometer with an SMA connector. The other end is placed closer to the object. When the body is directly heated during a high current impulse, it emits infrared radiation which is transferred by the optical fiber to the detector of the pyrometer. An accurate calibration procedure is required for the overall setup.

The low heat transfer coefficient and its immunity to electromagnetic waves make silica optical fibers suitable for transferring infrared emission without heat losses thereby functioning as a very efficient and fast measuring device. As an example, pure silica core and fluorine doped silica clad optical fiber with low-OH-group content is suggested for such measurements.

The proposed temperature measurement method can be applicable for a wide range of field-assisted sintering techniques (FAST).

Basic concepts of fiber-optics.

Fundamental laws of optics

The most important optical parameter of any transparent medium is its refractive index n. It is defined as the ratio of speed of light in vacuum (c) to the speed of light in the medium (v). That is,

$$n = \frac{c}{v} \qquad (1.1)$$

As v is always less than c, n is always greater than 1. For air, $n = n_a \approx 1$.
The phenomenon of refraction of light at interface between two transparent media of uniform indices of refraction is governed by Snell’s law. Consider a ray of light

passing from a medium of a refractive index n_1 into a medium of refractive index n_2 (see below). Assume that $n_1 > n_2$ and that the angles of incidence and refraction with respect to the normal to the interface are, respectively, Φ_1 and Φ_2. Then according to Snell's law,

$$n_1 \sin \Phi_1 = n_2 \sin \Phi_2 \qquad (1.2)$$

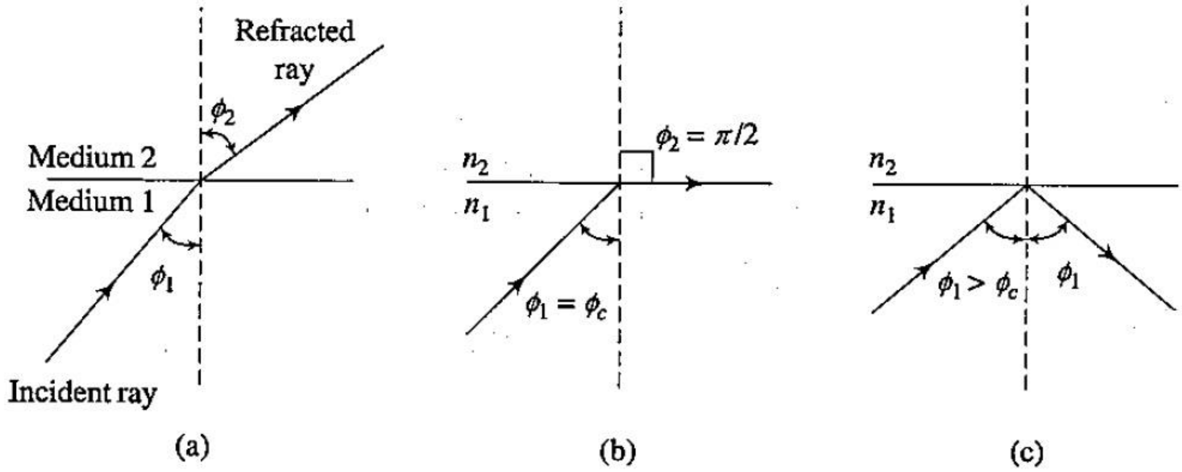


Fig 1 (a) refraction of a ray light. (b) Critical ray incident at $\Phi_1 = \Phi_c$ and refracted at Φ_2=π/2.

(c) Total internal reflection $\Phi_1 > \Phi_c$

As $n_1 > n_2$, if we increase the angle of incidence Φ_1, the angle of refraction Φ_2 go on increasing untill a critical situation is reached, when for a certian value of Φ_1=Φ_c, Φ_2 becomes $\frac{\pi}{2}$, and the refracted ray passes along the interface. This angle Φ_1=Φ_c, is called the critical angle. If we substitute the values of Φ_1=Φ_c, and $\Phi_2 = \frac{\pi}{2}$ in equation (1.2). we see that

$$n_1 \sin \Phi_c = n_2 \sin(\frac{\pi}{2}) = n_2$$

Thus $$\sin \Phi_c = \frac{n_2}{n_1} \qquad (1.3)$$

If the angle of incidence Φ_1 is further increased beyond Φ_c, the ray is no longer refracted back into same medium (see Fig). (this is ideally expected. In practice, however, there is always some tunneling of optical energy through this interface. The wave carrying away this energy is called *evanescent wave.* This can be explained in terms of electromagnetic theory). This is called **total internal reflection**. It is this phenomenon that is responsible for the propagation of light through optical fibers.

Using optical fiber for measurement ultrafast changing temperature non-contact method

Basics on temperature measurement principle of the pyrometer.

Measurement of temperature of the metal-ceramic compact during ultrafast sintering is very important to understand the physical and chemical properties of such a non-equilibrium process. Among the existing methods for temperature measurement, the optical fiber thermometry methods based on the Radiation temperature measurement of bodies at high temperatures are significantly being developed. Traditional conventional temperature measurement techniques based on thermocouples are simple to use but they have many limitations and in case the sintering is operated by electrical impulse thermocouples suffer electromagnetic influence. Optical fiber thermometry (OFT) has many advantages as immunity to electromagnetic influence, measurement range, stability, and the possibility of remote control for application in ultrafast high-temperature measurement under harsh conditions. In general, they are black body OFT, fluorescent OFT, and Noncontact OFT. Fluorescent OFT is based on fluorescent lifetime or fluorescence intensity of materials and is suitable for lower temperature ranges since lifetime and magnitude of intensity are decreasing with temperature growth. On the contrary, for higher temperature measurements blackbody OFT's are more sensitive. The combination of fluorescence and blackbody OFT is usually more expensive and complicated. Noncontact OFT is suitable to use at various temperature ranges but the accuracy is lower in comparison with blackbody OFT. Nevertheless, it has many advantages over contact-based OFT owing to the response time is very short, no need for impact with hot objects, and long service life under harsh environments. Therefore, for in-situ measurements of temperature during the sintering process preferable to apply noncontact optical fiber thermometry where the spectral power of photonic signals of Infrared Radiation emitted from the heated body is measured. The temperature is determined based on the generalized Plank's law which describes spectral power of blackbody thermal radiation

$$I(\lambda) = \frac{\chi C_1}{\lambda^5(exp(C_2/(\lambda T))-1)} \quad (4.1),$$

where χ is optical path factor determined by the product of emissivity ε and transmission coefficient τ of the medium through which the infrared emission arriving from the surface of the object; $C_1 = 2hc_0^2$ and $C_2 = hc_0/k$ are first and second radiation coefficients of blackbody; λ is wavelength and T is temperature. If optical fiber is used as medium between a hot object and input of pyrometer then transmission coefficient of optical fiber should be calculated. We can related the transmission coefficient τ with the Attenuation $A(\lambda)$ (dB/m) of optical fiber

$$\tau(\lambda) = 10^{-0.1A(\lambda)\cdot l} \quad (4.2)$$

where l is the length of optical fiber in meters. Thus equation (1) becomes

$$I(\lambda) = \frac{10^{-0.1A(\lambda)\cdot l}\cdot\varepsilon\cdot C_1}{\lambda^5(exp(C_2/(\lambda T))-1)} \quad (4.3)$$

Thus $I(\lambda)$ will be related also to the length of fiber. Taking into account that pure silica core optical fibers have excellent transmission properties in IR region, the influence of the length of fiber should be negligible at several meters of a fiber. However, it should be taken into account during re-calibration.

Advantages of non-contact method of temperature measurement using fiber optic pyrometer.

Noncontact temperature measurement is that the preferred technique for little, moving, or inaccessible objects; dynamic processes that needed fast response; and temperatures <1000°C (1832°F). To select perfect noncontact temperature measurement device for a specific application, it is essential to know the fundamentals of temperature measurement technology, temperature measurement parameters, and therefore the features offered by the various measurement systems currently available.

ISR 50-LO INFRATHERM-Pyrometer

Produced by Lumasense Technologies Comany (Germany). It measures temperature by non-contact. Measurement range 800-3000°C.

Fig 2 ISR 50-LO INFRATHERM-Pyrometer

Technical data of ISR 50-LO INFRATHERM-Pyrometer

Temperature ranges:	700 ... 1800°C (MB 18) 800 ... 2500°C (MB 25) 1000 ... 3000°C (MB 30)
Sub range:	any range adjustable within the temperature range, minimum span 51°C
Spectral ranges:	channel 1: 0.9 µm channel 2: 1.05 µm
IR detector:	Silicon foto diode (Si/Si)
Fibre:	MB 18: HD multi fibre 0.6 mm (green fibre mark) MB 25: HD mono fibre 0.2 mm (red fibre mark) MB 30: HD mono fibre 0.1 mm (yellow fibre mark)

Power supply:	24 V DC (18 ... 36 V DC), ripple < 500 mV
Power consumption:	Max. 1 W
Analog output:	0 ... 20 mA or 4 ... 20 mA (linear), switchable; Test current 10 mA or 12 mA by pressing test key
Load:	0 ... 500 Ω
Digital Interface:	RS232 or RS485 addressable (half duplex), switchable; baud rate 1200 up to 115200 Bd
Resolution:	0.1°C on interface and display; < 0.1% of temperature range at the analog output
Isolation:	power supply, analog output and digital interface are galvanically isolated from each other
Internal LC display:	LC display for temperature indication or parameter settings

Parameters:	Adjustable or readable at the instrument or via interface: Measuring temperature, operation mode (*ratio / mono*), emissivity slope *K* or emissivity ε, exposure time t_{90}, clear times t_{clear} for maximum value storage incl. automatically or external deletion of maximum value storage, or hold function, analog output 0 ... 20 or 4 ... 20 mA, sub range, switch-off level, contamination limit, RS485 address, baud rate, RS485-wait time t_W, temperature display in °C or °F, error status, maximum internal temperature
Emissivity slope K:	0.8 ... 1.2 adjustable in steps of 0.001
Emissivity ε:	5 ... 100% adjustable in steps of 0.1%
Switch-off level:	2% ... 50%, adjustable
Exposure time t_{90}:	10 ms; adjustable to 0.01 s; 0.05 s; 0.25 s; 1 s; 3 s; 10 s
Maximum value storage:	Built-in single or double storage. Clearing with adjusted time t_{clear} (off; 0.01 s; 0.05 s; 0.25 s; 1 s; 5 s; 25 s), extern, via interface or automatically with the next measuring object
Switch contact Opto relay (AC/DC):	Switch contact for dirty window alarm max. switch current 0.5 A max. switch supply 60 V AC/DC

Uncertainty: (ε = 1, t_{90} = 1 s, $T_{amb.}$ = 23°C)	up to 1500°C: 0.5% of measured value in °C + 2°C above 1500°C: 1.0% of measured value in °C
Repeatability: (ε = 1, t_{90} = 1 s, $T_{amb.}$ = 23°C)	0.2% of measured value in °C + 2°C
Ambient temperature:	0 ... 50°C at the converter 0 ... 250°C at optical head
Storage temperature:	-20 ... 60°C

Appropriate use

The pyrometers ISR 50-LO may be a digital, highly accurate 2-color pyrometer with fibre optic for non-contact temperature measurement on metals, ceramics, graphite etc. in temperature ranges between 700 and 3000°C.

The pyrometer measures within the 2-color principle (ratio principle) during which two adjacent wavelength are used to calculate the temperature. This technique offers the subsequent advantages compared with the quality one-color pyrometers:

• The temperature measurement is independent of the emissivity of the thing in wide ranges

• The measuring object are often smaller than the spot size.

• Measurements are unaffected by dust and other contaminants within the sector of view or by dirty viewing windows

Additionally the pyrometer are often switched to 1-color mode and used sort of a conventional pyrometer.

The instrument is provided with an glass fiber, which may be utilized in very high ambient temperatures up to 250°C without cooling and it's unaffected by electromagnetic interferences

Optical head

The instrument is going to be delivered with a HD optical head which is specially designed to attach a HD fiber.

This optic has got to be adjusted ex works to the specified measuring distance (possible range is 340 … 4500 mm, the measuring distance is usually measured from the front of the lens). Only in this distance the spot sizes mentioned in the table 7.1 will be achieved. A tape will be used to find the distance between object and pyrometer. Decreasing or increasing the measuring distance enlarges the spot size. Spot sizes for intermediate distances, that are not shown on the optical profiles, could also be calculated using the subsuquent formula:

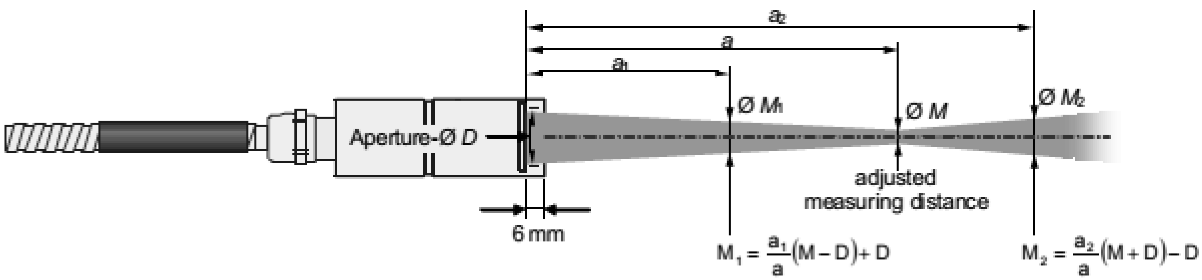


Fig 3 measurement distance

Table Measuring distance / spot size

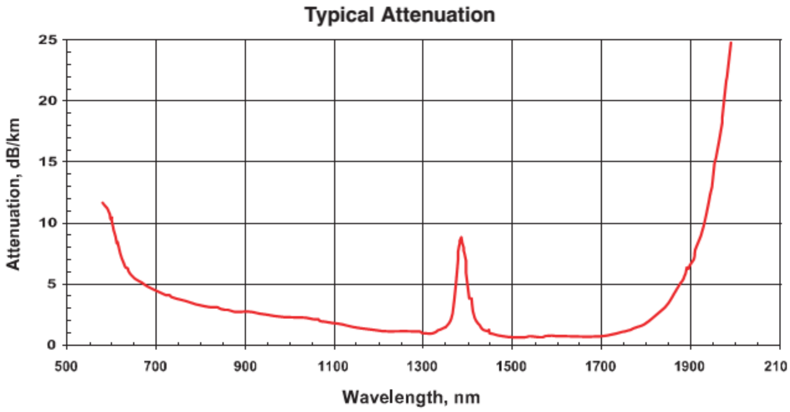
Measuring distance *a* [mm]	Spot size M_{90} [mm] 700 … 1800°C (MB 18) (green marked fibre)	800 … 2500°C (MB 25) (red marked fibre)	1000 … 3000°C (MB 30) (yellow marked fibre)	Aperture *D* [mm]
340	5.1	1.7	0.9	17
600	9	3	1.5	17
1000	15	5	2.5	17
4500	66	22	11	17

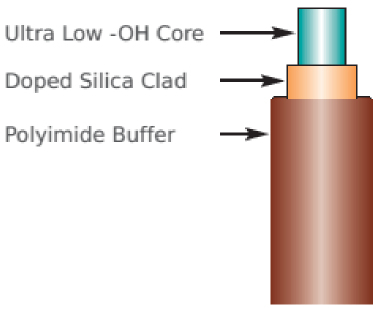
M_{90}: Spot size *M* focusing to the measuring distance „a" for 90% of the radiation.
D: The aperture is the effective lens diameter of the optics

FIP300 OPTICAL FIBER Characteristics

1. Step index
2. Numerical aperture: 0.22 ± 0.02
3. Full acceptance cone: 25.4 degrees

4. Vis-NIR transmission, 380nm to 2,200nm
5. High laser damage threshold
6. Sterilizable and bio-compatible – USP class VI*
7. Low-OH silica core, doped silica clad
8. Polyimide buffer standard; silicone, acrylate, high-temperature, acrylate also available.
9. Polyimide concentricity < 3μm
10. Sizes for bundling
11. Tighter tolerances available
12. Operating temperature: –65° to +300°C
13. Intermittent, up to 400°C
14. Proof tested to 100kpsi





Specifications:

Product Descriptor	Core (μm)	Clad (μm)	Buffer (μm)
FIP300330370	300 ± 6	330 ± 7	370 ± 7

Design of experimental setup

Used tools for an experiment:

1) IMPAC ISR50-LO pyrometer
2) Computer for controlling pyrometer and monitoring temperature change

FIP300 multimode optic fiber core diameter 300 μm and cladding diameter 330 μm.

3) Stable current source (It control constant electric current and voltage)
4) Halogen lamp as a light source.
5) Arduino microscheme for supplying light signals.
6) SMA905 connectors

Aim of the experiment

The main aim of the experiment is to prove that, in extreme environments to measure temperature of hot objects more accurate. It is clear that thermal sensors can measure accurately at transparent environment and also demand exact position from target for their spots. There are some kind of processes which are progressing in extreme conditions like welding, radiation, reactions and etc. at this experiment I'm going to show the benefit of optic fiber to measurement of temperature, and to find the difference between two results

Results of measurement of the temperature using standard method.

Firstly we measure temperature of lamp with only sensor itself. The light (5) comes to lenses (4) of pyrometer and pass through optic cable (3) to pyrometer screen (2) which shows temperature. For monitoring temperature change during time computer is used. For control and change some parameters like frequency, time intervals and other parameters INFRAWIN program is used. We should also observe in case of light changing process like welding, and this condition is arisen by using Arduino micro scheme. This scheme supply current pulses regularly, and do lots of sparks in one second which causes temperature change. The scheme of tools as follows:

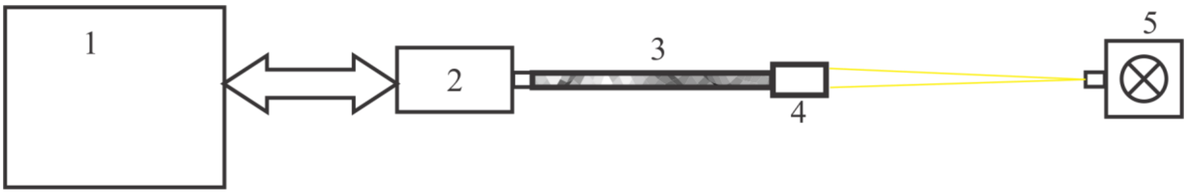


Fig 4 scheme of pyrometer lens 1) Computer; 2) IMPAC 50-LO pyrometer; 3) optic cable of pyrometer; 4) lenses system; 5) Lamp.

At first case the voltage of electric source is U=6.14 V and current I=1.048 A and temperature T=1727°C.

The graph of temperature versus time is shown below:

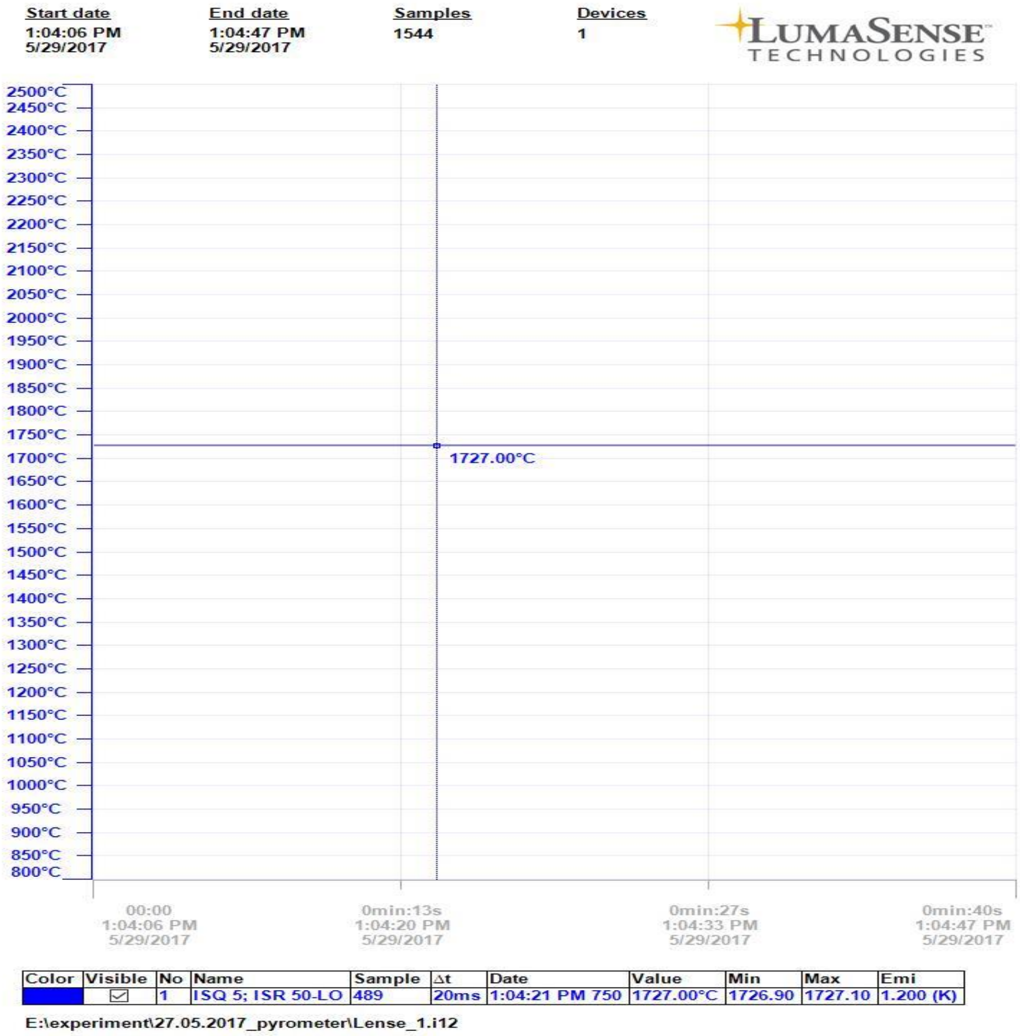


Fig 5 Temperature result of pyrometer lens.

Measurement results using optical fiber

At second case we add FIP300 optic fiber to sensor by using SMA905 optic connectors as shown in figure. For this condition all parameters are the same with previous case. The result is T=1667 °C. the difference is due to light reflections and intensity lost in optic fiber and also the surface roughness of the cross section of optic fiber.

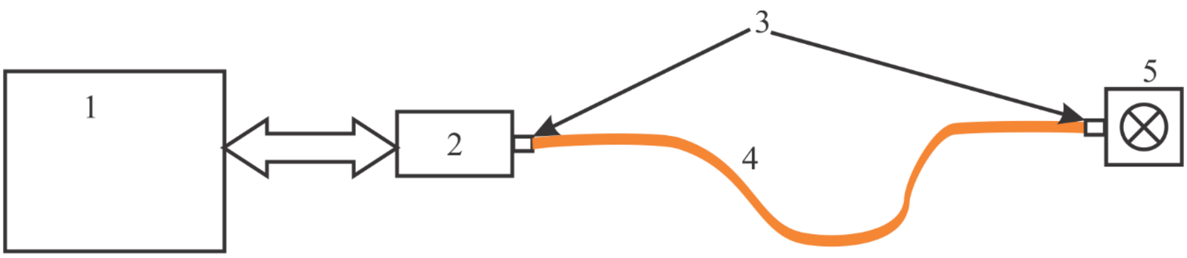


Fig 6 scheme of pyrometer with optic fiber 1) computer; 2) IMPAC 50-LO pyrometer; 3) SMA905 connectors; 4) FIP300 optic fiber; 5) Lamp

Fig 7 Measurement process

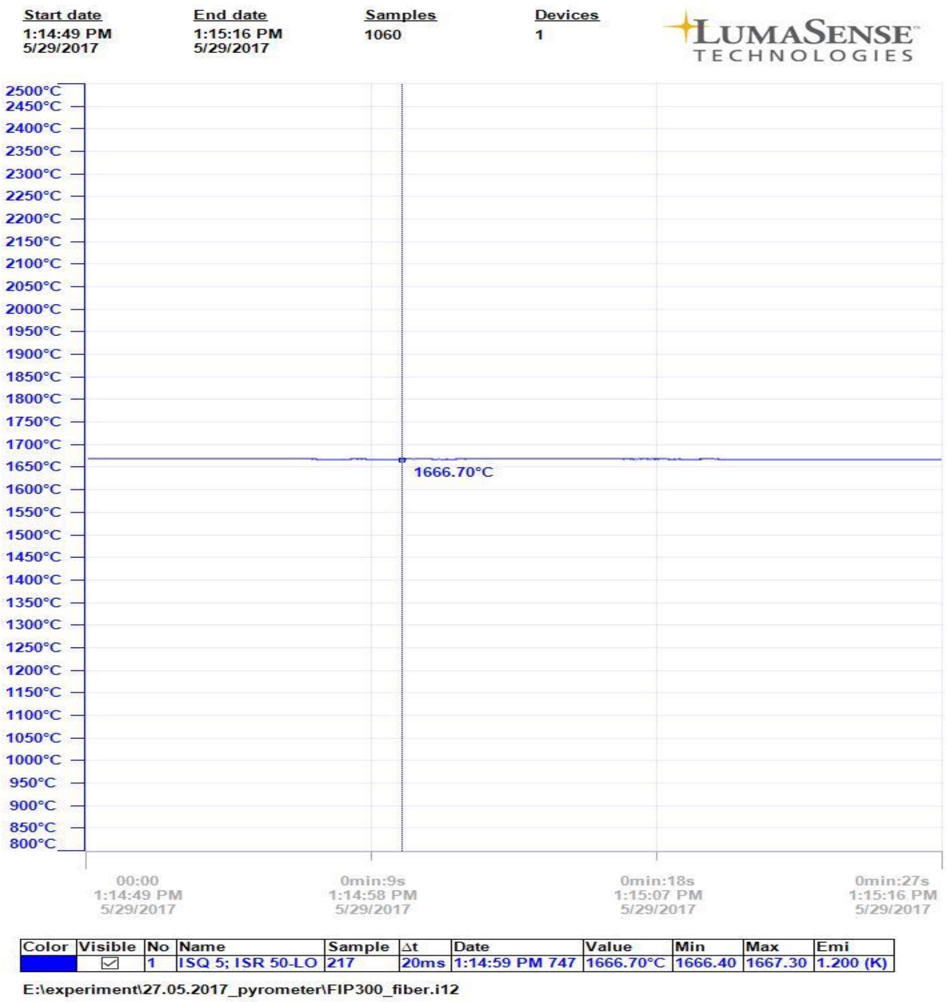


Fig 8 Temperature result of pyrometer with FIP300 optic fiber.

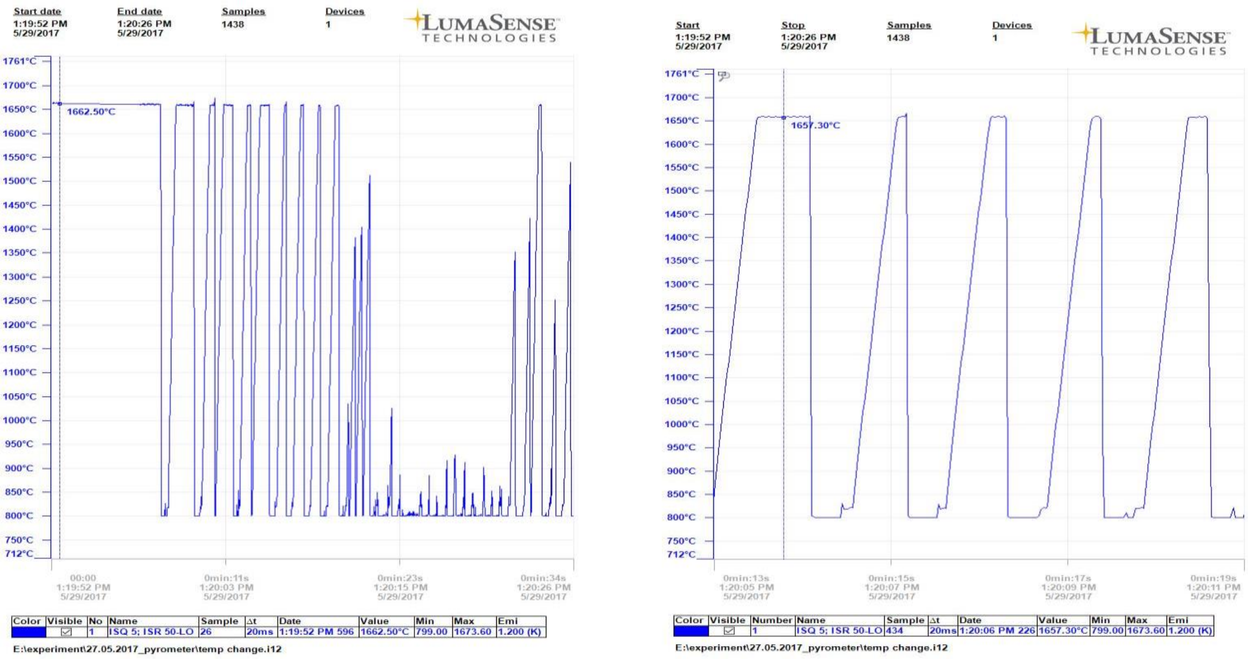


Fig 9 (a) Temperature change when light source is switch on-switch off. Fig 9(b) Temperature transient during the light is blinking

Fig 4.9(b) shows the temperature transient during the light is blinking. We can see that, temperature is increasing during approximate 0.6 seconds, but its drop is happening suddenly. Also there is such kind of parts of graph that temperature fluctuate. This is because of some changes on lamp spiral during heating.

Conclusion

Optical fiber has unique properties that makes it the base material for transfer optical light applied for ultrafast measurement system. Optical fibers can be used both as sensor and transfer medium of thermal radiation emitting from the surface of a hot body. There are many situations in Industry where some transient processes require temperature monitoring. As an example, we can say about fast sintering process of powder with metal content, welding and other situations where it is necessary to measure the fast change of the temperature of the hot object which is located in inaccessible environment.

Ultrafast temperature changing process during welding, sintering of powder material, and radiation reactions occur with the rapid change of the temperature within microseconds. The intensity of the thermal radiation which is Infrared photonic signal is proportional to the temperature thus measuring the Intensity of thermal radiation we can observe the temperature kinetics. The proposed measurement setup is based on the use of silica optical fiber as a transfer medium of thermal radiation up to the detector (pyrometer). The analysis of properties and types of present available optical fibers it was concluded that for higher temperature regions around 1500°C it is better to use pure silica core and fluorine doped silica clad optical fiber with low-OH group content. This kind of fiber has good transmission for IR region of spectra and withstand higher temperatures that makes it possible to use in such regions where traditional thermometers are useless. Besides the transfer of IR photonic signals is extremely fast, the fiber can be placed near the hot object without being in contact. The setup can be used in sintering process to obtain in-situ the thermal radiation signals from inaccessible area. The experimental setup has been tested in the Laboratory and showed good results. Further calibration measurements is required in order to obtain the temperature values, for monitoring the temperature kinetics the setup can be used.

Bibliography

1. Y. B. Yu and W. K. Chow, “Review on an Advanced High-Temperature Measurement Technology: The Optical Fiber Thermometry,” Journal of Thermodynamics, vol. 2009, Article ID 823482, 11 pages, 2009. doi:10.1155/2009/823482.
2. L.G.Dubas, “Technical Physics”, 2013, Vol. 58, No. 1, pp. 127–131.
3. V. C. Fernicola and L. Crovini, “Digital optical fiber point sensor for high-temperature measurement,” Journal of Lightwave Technology, vol. 13, no. 7, pp. 1331–1334, 1995.
4. R. R. Dils, “High-temperature optical fiber thermometer,” *Journal of Applied Physics*, vol. 54, no. 3, pp. 1198–1201, 1983.
5. K.T.V.Grattan, Fiber optic techniques for temperature measurement, “Optical Fiber Sensor Technology”, Volume 1, 1995, pp 441-459.

6. B.H.Kristen, L.M.Gary et.al, Microwave sintering of Alumina at 2.45 GHz, J. Am. Ceram. Soc., 86 (8) 1307-12 (2003).

7. Radiometric Temperature Measurements: I. Fundamentals, Ed. by Z. M. Zhang, et al., Exp. Methods Phys. Sci. (Elsevier, Amsterdam, 2009), Vol. 42.

8. Radiometric Temperature Measurements: II. Applications, Ed. by Z. M. Zhang, et al., Exp. Methods Phys.Sci. (Elsevier, Amsterdam, 2010), Vol. 43.

9. Procedure for calibration and verification of the main characteristics of thermographic instruments, OIML R 141 Edition 2008 (E).

10. K. T. V. Grattan and Z. Y. Zhang, Fiber Optic Fluorescence, Thermometry, Chapman & Hall, London, UK, 1995.

11. R. R. Sholes and J. G. Small, "Fluorescent decay thermometer with biological applications," Review of Scientific Instruments, vol. 51, no. 7, pp. 882–884, 1980.

12. K. T. V. Grattan and A. W. Palmer, "A fiber optic temperature sensor using fluorescence decay," vol. 492 of Proceedings of SPIE, pp. 535–542, 1984.

13. Introduction to Thermodynamics and Heat Transfer, Second Edition Yunus A. Çengel 2008

14. Introduction to Thermal Systems Engineering: Thermodynamics, Fluid Mechanics, and Heat Transfer by John Wiley & Sons, Inc. 2003