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Utilization of Layered FBG (*Fiber Brag Grating*) as a Methane and Carbon Dioxide Gas Sensor

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ABSTRACT

The use of gas sensors has grown rapidly and has driven much research related to the use of gas sensors in various fields including medical, industrial and military applications. Electronic sensors have dominated sensor technology for decades. However, some features of conventional sensors require significant improvement, e.g. B. in sensitivity to electrical noise, multiplicity of wires, etc. Because of these drawbacks, researchers around the world have invested heavily in improving conventional sensors. Therefore, these efforts resulted in a new generation of different sensors, including fiber optic technology. FBG sensors, a type of point sensor, are one of the most widely used FOS. The basic principle of operation of FOS and FBG sensors is the reflection and filtering of different wavelengths of light. In FBG sensors, the fiber optic lattice feature allows transmission of all wavelengths except specific reflected wavelengths. This process is called optical lattice resonance. In the next section, a brief introduction to the theory of fiber optic sensors used in this study is given, with a particular focus on FBG. The basic principle of operation of FOS and FBG sensors is the reflection and filtering of different wavelengths of light.

Keywords : *Gas sensor, Utilization, How it works*

1 Introduction

FBG optical sensors have been developed that exploit load-induced wavelength changes. This load causes a bending phenomenon in the material under test. The way the FBG sensor works is to measure the reflection of the bragg wavelength (F. N. Hidayah and H. Haikal, 2022). Fiber optic bragg grating (FBG) has been recognized as an outstanding high-performance local monitoring sensor and is mostly applied in structural health monitoring (SHM) (Z. Zhou *Et Al*, 2016). The fiber bragg (FBG) grid is a part of optical fiber whose periodic refractive index is divided into grids (H.M Perdana and A. Firdaus, 2021)(L.Sun, *Et Al*, 2016). FBG reflects a certain wavelength of light and the rest is emitted in the other direction, which is possible due to periodic variations in the refractive index of optical fibers. (D.P Sutriyono and Saktioto, 2017) .

The benefits of using this sensor are its high precision and sensitivity, measurements are made directly, sensitivity to low light is minimal, short response time, and immune to electromagnetic fields (F. N. Hidayah and H. Haikal, 2022)(A. Barrias, *Et Al,* 2016). FBG which has a periodically changing refractive index grid has received great attention in recent years, FBG can be used as an optical filter, dispersion compensation in optical communications, and optical sensor (D. Irawan, *Et Al*, 2022)(T. Saktioto, *Et Al*, 2021). An operational, *Fiber Bragg Grating* (FBG)-based sensing systems specifically designed to monitor harsh conditions of industrial environments are reported to be relatively high humidity in *North Head* sewage treatment plant in Sydney, Australia (B.Rente *Et Al*, 2021).

FBG characterization is usually done by applying temperature changes to the FBG directly using a heated light bulb or plate. The properties of FBG have been studied and result in lower FBG output power compared to the increase in temperature (Y.N Azizah and Saktioto, 2020)(G. Prajitno and R.I Yunifar, 2015) .

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2 Research Methodology

Based on the sources we used for this article, below is a schematic interpretation of the structure of FBG and the spectrum of light flowing through FBG related to this article:

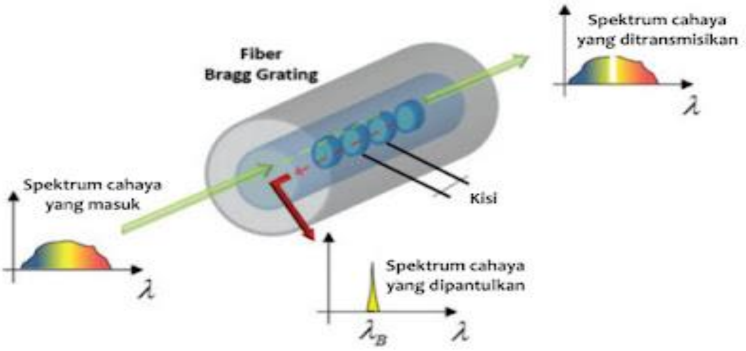


Figure 1 : FBG Structure and Light spectrum passing through optical fiber

If the distance between grid values is even or even, then FBG is said to be even. When the distance between the grids is greater (more than 100 μm) it is said to be a long-period FBG, but when the distance and position of the grid is even it is called oblique FBG. There are other types of F BG such as B. FBG chirp where the distance between the grids is increased, FBG shifts phase when the distance between the grids is selected in such a way that they can change the phase of light waves by pi (π), FBG superlattice when the grid distance is certain.

2.1 Fiber Optic Sensor Spectroscopy

In general, spectroscopic techniques have been applied to optical sensors and fiber sensors relatively successfully in gas detection applications. Supports two main mechanisms of this type of sensor. The first uses fairly standard spectroscopic techniques: Gas absorbs incident optical radiation of a specific wavelength (T. Allsop and R.Neal, 2021) (J. Shi *Et Al*, 2017). the other is the direct interaction of fleeting fields, the memory at the interface between the waveguide interface (guided supported, leaked or both) and the surrounding material, in this case optical fibers, waveguides and surrounding gas media. The interaction can be enhanced by limiting the controlled space to the physical volume of the fibers. This boundary spatially extends the fading field to its temperate environment (gas), which increases sensitivity (T. Allsop and R.Neal, 2021) (R. Senthil *Et Al*, 2021).

Raman Resonance Spectroscopy (RRS) occurs when the energy of the incident photon is equal to the energy of the excited state of the electronic vibration of the gas. This energy adjustment can lead to an increase in the intensity of Raman scattering, which has been applied in the study of small molecule chemical compounds. Finally, in this section, we include surface enhanced Raman spectroscopy (SERS) as shown in Figure. 1. The interaction between the incidence of optical and gas energy occurs on a flat metal surface with nanostructures inside the fiber. The exact interaction between incident optical and gaseous energy is currently being studied to fully understand the mechanisms involved. There is increasing evidence that radiation excites local surface plasmons (LSPS) on metal surfaces. There is also evidence that plasmons are sensitive to the shape, size, and orientation of surface irregularities and contribute to the conversion of optical energy (photons) into mechanical energy (phonons) and thus into Raman scattering. Variations in surface patterns alter the response of SERS, meaning the device is capable detects chemicals and gases (T. Allsop and R.Neal, 2021).

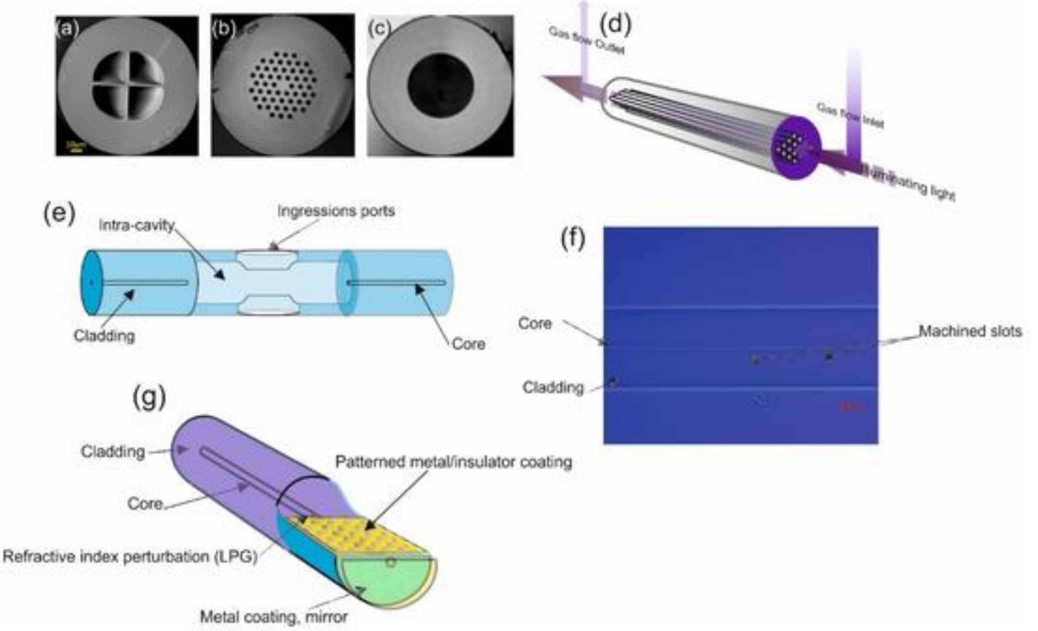


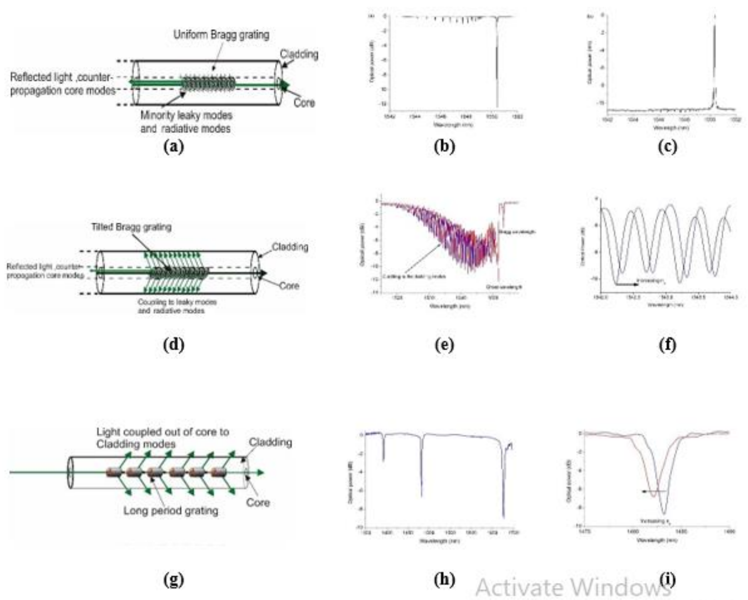
Figure 2 : Typical scheme of various sensors: fiber optic spectroscopy

Various images of different types of photonics fiber optic crystals: (a) grapefruit, (b) large fashion area photonic crystal fibers, (c) hollow optical fibers; capillary fibers. (d) Operating scheme of photonic crystal optical fiber as gas sensor. (e) An intra-cavity fiber optic scheme for gas sensing, which will utilize capillary fibers. (f) Micromachine microscope image of a femto-second laser cavity "slot" close to the fiber optic core. (g) Raman spectroscopic scheme of enhanced fiber optic surface (SERS) sensors. SERS uses nano-patterned materials such as nano/colloidal particles Au or Ag. Figure 1a is reproduced from D.

2.2 Fiber Optic Grid Sensor

Grid sensors are divided into bragg fiber grid (FBG), bragg inclined fiber grid (TFBG) and remote grid (LPG). The three sensors have something in common, namely that they have comb-like periodic structural variations in the refractive index inside the core fiber that induce a merging action between the core mode and other modes supported by the fiber. There are a number of different fabrication methods used; For example, ultraviolet (UV) phase mask inscriptions, UV point to point, femto-second laser direct write inscriptions, and fusion arcs.

The problem with using FBG is that they are inherently insensitive to changes in media roundness. This is reflected in the phase matching conditions of FBG, which is the maximum resonance wavelength and reflectivity of the lattice, where neff is the effective index of the core mode, L is the period of the bragg fiber lattice, L is the length of the lattice. and k is the coupling coefficient). The general sensitivity of conventional FBG, written in fiber optic step index, is 1.2 pm/με. An FBG coated with palladium can be used to detect hydrogen genes using ε parameters. However, another example is removing fiber cladding by polishing or etching it into close proximity to the core so that the fleeting field of memory from the core mode is exposed to the surrounding medium, changing the gradual matching of the FBG condition, using the Sf parameter (T. Allsop and R.Neal, 2021) (J.K Sahota *Et Al,* 2020) (J. He *Et Al*, 2021).



Picture 3 : Three types of fiber lattice sensors and their spectral response

(a) Bragg fiber grating scheme. (b, c) The spectral response of the Bragg lattice of fibers is typical in reflection and transmission. (d) Beveled fiber Bragg lattice scheme. (e, f) The spectral response of the bragg grille of oblique fibers is typical in transmission and response to changes in the index of the surrounding medium. (g) Long-period grid scheme. (h,i) Spectral responses in transmission and responses to changes in the index of surrounding media.

3 Results and Discussion

3.1 Methane

Methane gets more public attention because it plays a bigger role in the greenhouse effect than carbon dioxide. There are many published works using absorption spectroscopy related to molecular transitions in the near and middle infrared spectra and applied to cavities such as hollow fibers or microstructured fibers. Methane has an infrared absorption band, υ2+2υ3 band at 1333 nm and 2υ3 band at 1666 nm. The methane band υ2 + 2υ3 is a weak absorption line and has additional measurement problems due to cross-sensitivity with water vapor.

The absorption band at 1666 nm is quite strong, exhibits minimal cross-sensitivity to other gases and is much stronger than the υ2+ 2υ3 band. The 1666 nm line is preferred for spectroscopic measurements. The main problems with spectroscopic observation techniques are long gas diffusion times, charging times (about an hour), and complicated equipment that is not easy to transport or durable. In addition, the spectral response of some of the wells used can be complicated by spectral features such as visible edges at the sensor output, limiting resolution, and detection accuracy.

Another important strategy for detecting methane is chemisorption. It is a chemical reaction on the surface of the membrane that changes the optical properties of the membrane. Usually, this strategy is used in conjunction with other types of sensors (already mentioned). Zinc oxide reacts mainly with methane. First, the oxygen molecule pulls electrons from the conduction band ZnO and forms O2−. It forms ZnO species: O2− on the surface of ZnO; It is known that methane decomposes into C0H3 and 0H, with radial hydrogen reacting with O2− but with high activation energy. Therefore, it must be operated at temperatures above 200°C.

The decrease in activation energy (decrease in Gibbs free energy) is achieved by using catalytic node metals such as palladium-silver or platinum-ZnO that are surface activated. It is basically a redox reaction that leads to a reduction in ZnO permittivity. Tin(IV) oxide (SnO2), an n-type semiconductor, has been shown to alter methane permittivity when methane molecules act as reducing agents by donating electrons to SnO2 films and graphene to absorb methane use.

The use of methane-sensitive membranes containing cryptophane molecules has proven to be a useful technique for methane detection. These are organic supramolecular compounds with a large number of carbon atoms and an aromatic ring structure. The cryptophane molecule is cage-shaped, and the top and bottom of the cage consist of aromatic ring units. The central (bridge) part of the cryptophane consists of other organic molecules that provide hydrophobic pockets of the shell that can be modified in various shapes, volumes, and chemical properties, making cryptophones suitable for encapsulation of various types of small molecules and even chemical reactions. More specifically, in the case of cryptophane E molecules, functional materials that have direct photosensitive properties to methane, when the methane molecule enters the cage, the dipole moment of the cryptophane molecule changes, resulting in a change in permittivity and hence a change in the refractive index. The molecule Cryptophane E. This approach is relatively new and promising. The work was published using cryptophane E with sensors operating at ambient temperature and cryptophane A was chosen as a methane-sensitive membrane.

Recently, graphene and/or carbon nanotube (CNT) coatings combined with polymers with base node metals have been used, especially for the manufacture of sensors for methane detection. The outer layer is sometimes referred to as a nanocomposite, where graphene and/or CNTs provide a large surface area to react with the environment, and polymers are used to produce a selective response to methane. Polymers reported so far include poly(methyl methacrylate) and the use of reduced graphene oxide. Other polymers have also shown success in chemical selectivity with methane, such as poly(acrylic acid) carbon nanotubes/polypropylene amine hydrochloride, which work with cryptophane molecules.

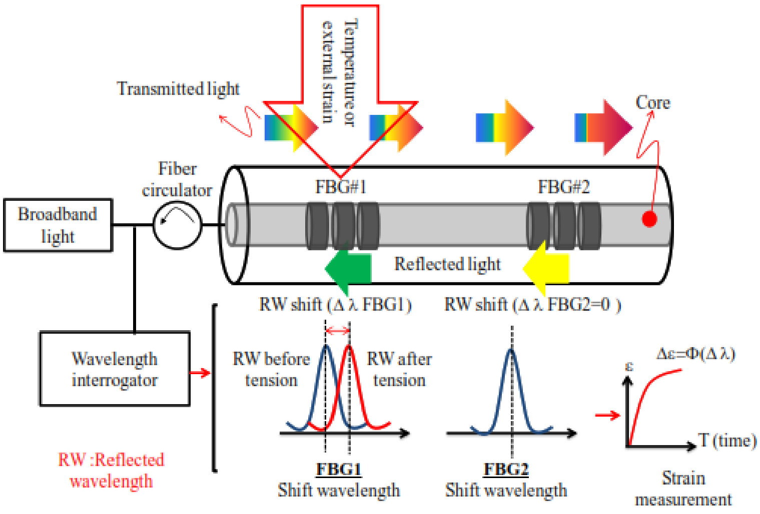
3.2 Carbon dioxide

Spectroscopic techniques for detecting carbon dioxide have improved significantly. The most important absorption wavelengths are near and medium infrared as follows: The spectral band of the line is ~2.005 µm (R branch), ~2.015 µm (P branch), and the middle infrared absorption line is ~4.2 µm and ~2.6 µm. There are some interference problems because the water vapor absorption lines in the 2 µm and 6 µm regions cause crossover sensitivity and selectivity. Conventional SMF optical fibers lose sensitivity at longer wavelengths, resulting in high attenuation. Optical fibers with higher transparency at wavelengths between 1.5 µm and 10 µm have been developed, known as chalcogenide fibers [21]. This type of fiber has manufacturing problems and produces attenuation values of 0.1 to 0.5 dB/m, but has been found to emit moisture when used above 100°C.

An alternative method to spectroscopic techniques for CO2 detection is the use of additives with or on optical fibers that react specifically with CO2. Several different ingredients have been reported in the literature in recent years, such as xerogels treated with trisodium salts of 1-hydroxy-3,6,8-pyrenetetrasulfonic acid (HOTS), also known as pyranine. This CO2 sensor is based on pyranine, a pH-sensitive fluorescent indicator dye. In the presence of CO2, the dye exhibits absorption properties that alter the ion transfer of pyranins and xerogels at wavelengths of 396 nm and 460 nm, effectively reducing absorption at those wavelengths. This reaction occurs at room temperature and has a reasonable reaction time. Another approach uses oxidation or reduction reactions, where there is a process of electron transfer between gas and material. An example is hybrid nickel/reduced graphene oxide (NiO/rGO), a structured coating material.

The reaction wavelengths are 670 nm and 771 nm, and the combination of nanostructured materials and their chemical composition in the presence of CO2 triggers reactions that change the distribution of O, O2−, and O2 radicals in the material. changes the density of electrons and thus their permittivity. The result is a small but significant change in the wavelength of emissions. Redox reactions with single-walled carbon nanotubes (CNTs) have been used for CO2 detection. Chemical selectivity is referred to as activation energy, which has been lowered to allow room temperature operation. It is known that N2 can act as a redox agent for CNTs, but the activation energy of this reaction is high; therefore high temperatures above 500°C are required.

Another material studied and reported uses N,N,N0-tributyl pentamidine embedded in a polymer matrix of ethyl coatings, which work in conjunction with SPR-based sensors. CO2 penetrates into the polymer matrix and reacts with N, N, N0 and polymer networks, changing the electron density distribution and therefore permittivity, resulting in a change in the refractive index of the polymer network. Other coatings used are carbon aminopolylamine nanotubes machined with bare scratched FBG; Again, these are all redox reactions. Other researchers have created nano-porous metal-organic skeletons by growing cobalt zeolite imidazole (C-MOF) skeletons using zinc nitrate and cobalt nitrate hexahydrate in repeated processing cycles. The chemical selectivity of CMOS optical fibers is due to the special adsorption capacity of the layer itself to absorb large amounts of CO2, thereby changing the refractive index of the C-MOF layer. Single-mode fiber optic sensors coated with metal-organic (MOF) frames have been fabricated using different chemical components such as copper benzene nanopores-1,3,5-tricarboxylate and have shown promising results. There are many strategies for making CO2 gas selective fiber optic sensors.



Picture 4 : Working Principle Sensor measurement *Fiber Bragg Grating* (FBG)

Electronic sensors have dominated sensor technology for decades. However, there are some characteristics for which conventional sensors require significant improvement, including sensitivity to electrical noise, heavy cable overhead, etc. Because of these drawbacks, researchers around the world have invested heavily in improving conventional sensors. Therefore, these efforts resulted in a new generation of different sensors, including fiber optic technology.

In addition to FBG sensors, there are two types of distributed and widely used FOS, among which are Brillouin Optical Time Domain Analysis (ADWOB/BOTDA) and Brillouin Optical Time Domain Reflectometry (RDWOB/BOTDR) [23]. In FBG sensors, the fiber optic lattice function allows the transmission of all wavelengths except specific reflected wavelengths, a process called optical lattice resonance. In the next section, a brief introduction to the theory of fiber optic sensors used in this study is given with a special focus on FBG. The basic principle of operation of FOS and FBG sensors is the reflection and filtering of different wavelengths of light.

Table 1. Data on the effect of FBG coating on sensor sensitivity

No	Sensor Type	Sensitivity	Resolution	Reference
1	Sensor Fiber optics *Multimode U-Shaped* in heterodynamic interferometry	*6300 °/RIU*	*2 x 10-6*	(S.-F. Wang 2009)
2	Singlemode fiber *optic ubent* as field sensor magnet	*-0.421 dB/oe*	-	(Liu Et Al. 2014)
3	Ushaped multimode *optical fiber* as sensor water salinity	-	*1 x 10-3*	(Stupar et al., 2012)
4	Fiber optic plastic POF *ubent* as refractive index sensor	*5.57 A/RIU*	*1 x 10-3*	(Gowri &; Sai, 2016)
5	U-bent *optical fiber* as LSPR biosensor	*35 A/RIU*	*3.8 x 10-5*	(Sai, Kundu, & Mukherji, 2009)
6	Fiber optic SMS *u-bent* as magnetic field sensor	*5.6 dB/mT*	-	(Zhang et al., 1882)

4 Conclusion

The conclusion of this study is that the use of FBG (Fiber Bragg Grating) layered on the sensor used placed in the tank is relatively high in use for current technological developments. In FBG sensors, the fiber optic lattice feature allows transmission of all wavelengths except specific reflected wavelengths. This process is called optical lattice resonance. In the next section, a brief introduction to the theory of fiber optic sensors used in this study is given, with a particular focus on FBG. The basic principle of operation of FOS and FBG sensors is the reflection and filtering of different wavelengths of light.

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