PHOTONIC NANOSTRUCTURED BRAGG FIBRE & APPLICATIONS

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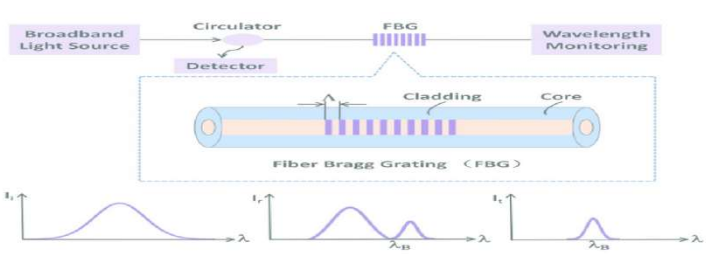
Abstract: In developing technologies, Bragg fibre & Fiber Bragg Grating (FBG) is crucial for optical communication and sensing applications. This article focuses on the operation of fibre bragg grating sensors, various fabrication methods, numerous fibre bragg grating types, and current real-time applications, including undersea acoustics, the oil and gas industry, and structural health monitoring systems for aeroplanes. Many optical technologies, including optical fibre communication and sensing applications, are focusing more and more on one of the crucial optical components, such as Bragg Fiber. A FBG, which is included into a short fibre segment and functions as a type of distributed Bragg reflector, reflects specific light's wavelengths while transmitting all others. This is achieved by regularly changing the refractive index of the fibre core, which produces a mirror with a certain wavelength. The area of fibre optic communication witnessed revolutionary advancements due to the implementation of the fibre Bragg grating as the dispersion correction element.
Keywords: Photonic nanostructures, Bragg Fibre, Bragg Grating, Photonic Crystal

1. INTRODUCTION:

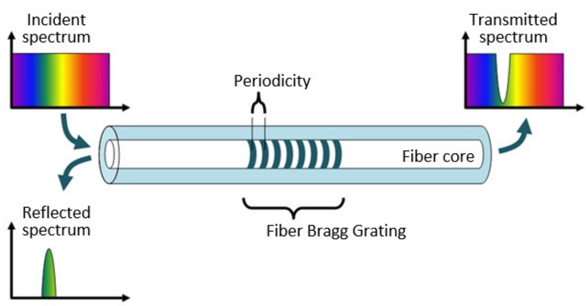
Philip Russell invented photonic crystal fibres in 1998, and they may be engineered to have superior qualities to (regular) optical fibre [1]. Optical fibres are the apex of telecommunications, capable of operating at greater bandwidths than electric cables and transforming long-distance communications. A core and a transparent cladding material with a lower refractive index make up an optical fibre. Total internal reflection is produced by the fiber's waveguide. As optical fibres developed to the point that they started to be used in modern sensing systems, bulk optics were required to steer the light, which led to the development of complex systems [2].



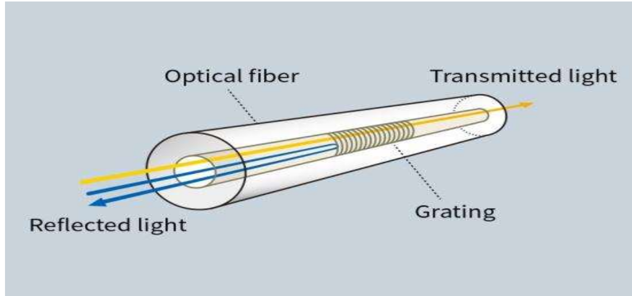
The advent of the laser was the most significant advancement in the area of fiber optic, but in 1978, Hill and colleagues developed a new approach called Photosensitivity, which brought about a new revolution in fibre technology. The mechanism of continuous refractive index and length change is known as photosensitivity [3].

The development of Fiber Bragg Gratings, another type of fibre, was driven by the discovery of photosensitivity (FBG). Since nanostructured fibres have been studied, a wider variety of fibre topologies are now possible, yet total internal reflection still governs light steering. It is known that the photonic bandgap (PBG) phenomenon allows light to be guided by fibres with two-dimensional (2D) photonic-crystal formations.

These fibres are constructed from common materials like polymers or silica glasses, but they also have air holes that might accommodate liquids. Applications are restricted to optical transmission and related phenomena due to the usage of electrically insulating materials and the presence of Compressible domains. We start by laying out the requirements for choosing appropriate material combinations and defining the steps involved in using a multi-material preform for fibre processing [4]. Then, we provide a fibre that creates a cylindrical unidirectional mirror by alternately layering electrically insulating polymer and semiconducting glass of various thicknesses on a regular basis. With sufficiently of an index difference between the layer materials, electromagnetic field penetration into the solid layers is reduced, resulting in a fibre that is significantly more transparent than the sum of its parts [5].

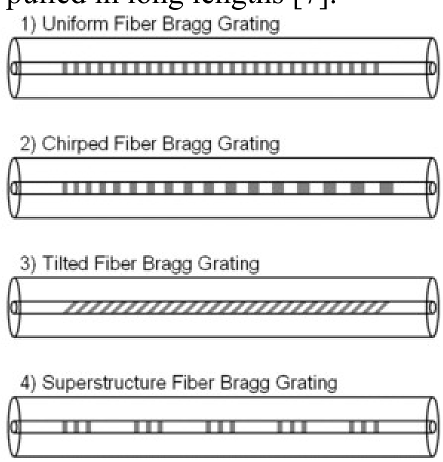


Fibre optics, sometimes called optical fibre, is a method that transmits data as pulses of light through a glass or plastic fibre. These glass fibres can range in quantity from a few to several hundred in a fibre optic cable. The glass fibre core is encircled by a second glass layer known as cladding. The buffer tube layer provides protection for the cladding and the last line of defence for each individual strand is the jacket layer. These glass fibres can range in quantity inside a fibre optic cable from a few to several hundred. The glass fibre core is encircled by a second glass layer known as cladding [6].

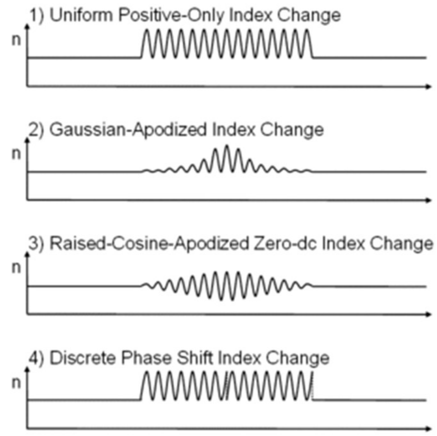


The cladding is shielded by the buffer tube layer, and the last line of defence for each individual strand is the jacket layer.

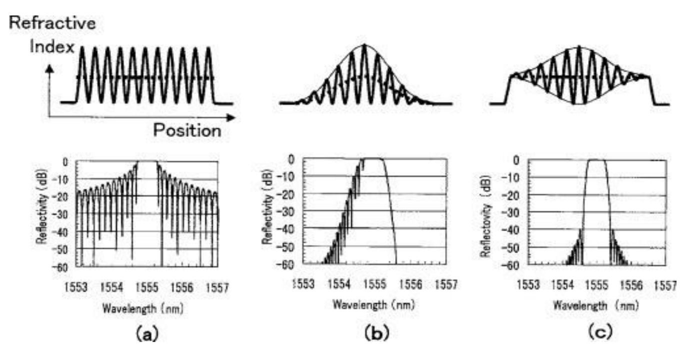
One of this structure's distinguishing qualities is that its elements are wavelength-scalable, meaning that the structure's period impacts the wavelength of light transmitted down the fibre axis. In order to make fibres that direct ultraviolet (UV), visible, near-infrared (NIR), or mid-infrared (MIR) light, the lattice constant of the periodic multilayer structure is simply changed. A large increase in surface area is produced when fibres are pulled in long lengths [7].



In turn, this opens up the possibility of developing fibre surface devices. High-efficiency fibre reflectors are made possible on very large surfaces by positioning the Omni directional mirror structure near to the fibre circumference [8]. Additionally, a radial resonant optical cavity fibre is created by appropriately inserting thickness changes in certain layers of the reflecting structure [9]. The impacts of building optical electronic and thermal fiber-based devices while simultaneously pulling metals, semiconductors, and insulators into the same fibre are then discussed [10]. Solid core metal-semiconductor-metal (MSM) and Thin-film junctions that detect thermal or optical stimulation.



These non-functional building blocks allow for fibre arrays, which combine numerous fibres into large-scale structures, as well as multifunctional fibres, which mix many building blocks into the structure. In order to create nano-structured planar multilayer stacks, multilayer claddings on rods with macroscopic diameters have been created using the fibre rolling procedure employed to create the fibres.



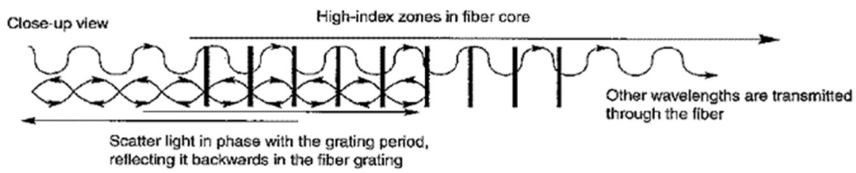
2. Principal of Operation:

Total internal reflection is used by an optical fibre, a cylinder-shaped dielectric waveguide (nonconducting waveguide), to carry light down its axis. A cladding layer surrounds a core, and both are made of dielectric materials. [11] Since the optical signal must be kept inside the core, the cladding's refractive index must be higher. In step-index fibre or graded-index fibre, the change from the core to the cladding can be rapid or progressive. Both lasers and LEDs have the capacity to transmit light across optical links. Electrical interference cannot affect fibre; neither can signal interference between cables or background noise. Nuclear-generated electromagnetic pulses have no effect on data travelling inside an optical link. In high-voltage environments like power plants or other places prone to lightning strikes, fibre cables are an excellent option for insulating communications equipment because they don't transport electricity. Additionally, the electrical isolation prevents ground loop problems. Since optical cables don't carry electricity that may potentially cause sparks, they can be used in locations with explosive gases. Wiretapping—in this case, fibre tapping—is more difficult than tapping electrical connections.

3. **Characteristics of Fibre Optics Bragg Fibre:**

3.1 Total Internal Reflection:

If light is passing through a thick optical medium when it makes a sharp angle collision with a barrier (greater than the critical angle for the barrier), it is completely reflected. This is what's known as total reflection. This effect is used to limit light in the core of optical fibres. Since most modern optical fibre is weakly guiding, the cladding and core's refractive indices differ just little from one another (typically less than 1 percent). Throughout the fibre core, light encounters the cladding-core interface many times.



Only light that enters the fibre between a particular range of angles may do so without leaking out, as the light must reach the border at an angle larger than the critical angle. The acceptance cone of the fibre is the collection of these angles. Light must enter the fibre at a certain maximum angle from the fibre axis in order to migrate, or propagate, into the fiber's core. The numerical aperture (NA) of the fibre is the sine of this greatest angle. Less accuracy is needed while handling and splicing larger NA fibre.

The discrepancy in refractive indices between the fiber's cladding and core determines the size of this acceptance cone. Single-mode fibre has a relatively low NA.

3.2 Attenuation:

In fibre optics, attenuation, sometimes referred to as transmission loss, is the weakening of the light signal as it passes through the transmission medium. dB per kilometre is a common unit of measurement for attenuation coefficients in fibre optics. A silica glass fibre serves as the standard definition of the medium, which houses the incident light beam. Attenuation is a significant barrier inhibiting the transmission of a digital signal over long distances. Due of this, it has been extensively studied how to maximise optical signal amplification while minimising attenuation. Over the course of 40 years, there has been a steady improvement in production techniques, raw material purity, perform, and fibre designs. As a result, the attenuation of silica optical fibres has decreased by four orders of magnitude, allowing them to get close to the theoretical lower limit of attenuation. [12].

3.3 Light Scattering:

Light travels through the core of an optical fibre due to total internal reflection of the lightwave. Rough and asymmetric surfaces can cause random light ray reflection even at the molecular level. This phenomenon is known as diffuse reflection or scattering, and a wide variety of reflection angles is typically used to identify it. Light passes through the core of an optical fibre using total internal reflection as its principal mode of propagation. Rough and uneven surfaces can cause light rays to reflect incorrectly even at the molecular level. This phenomenon, diffuse reflection, also known as scattering, is usually characterised by a wide variety of reflection angles. Scattering is influenced by the light's wavelength. The frequency of the incoming light wave and the physical size (or spatial scale) of the scattering centre, which typically manifests as some specific microstructural property, restrict the spatial dimensions of vision that occur. The wavelength of visible light, which is on the order of one micrometre (one millionth of a metre), will be identical because the scattering centres' diameters will be on a similar spatial scale.

The result of light being inconsistently dispersed at interior surfaces and interfaces is attenuation. Along with holes, grain boundaries, which separate tiny regions of crystalline order, in (poly) crystalline materials like metals and ceramics, are the most prevalent interior surfaces or interfaces. It has been determined that scattering stops occurring to any appreciable extent when the size of the scattering centre (or grain boundary) is decreased below that of the wavelength of the light being scattered. Transparent ceramic materials have previously been produced as a result of these processes [13].

3.4 Advantages and Disadvantages of Fiber Optics:

The benefits of fibre optic cables over copper cables are the key reasons why they are employed. A mong the benefits are the following:

- ➢ They enable greater bandwidth capacity.
- ➢ Light can go farther without requiring as much signal amplification.
- ➢ They resist interference, such as electromagnetic interference, better.
- ➢ •They are water-submersible.
- ➢ Due to its superior strength, light weight, and thinness compared to copper wire lines, fibre optic cables require less upkeep and repair

- ➢ Although fibre optics do offer some drawbacks that consumers should be aware of, it is cru cial to highlight that these drawbacks do exist

- ➢ Fibre optics are used for long-distance and high-performance data networking.

It is extensively used in other types of telecommunications as well, including the internet, television, and telephones.

For instance, Google Fiber and Verizon FIOS, the two companies' respective products, both use fibre optics to provide users with gigabit internet speeds.

3.5 **Drawbacks:**

- Compared to fibre optics, copper cable is frequently less expensive
- Glass fibre requires additional protection within an outer wire. New wiring requires a lot of labour
- Cables made with fibre optics are usually more fragile. For example, if the cable is bent or curved with a few millimetres of radius, the signal may be lost or the fibres may break

3.6 Fiber Optics Bragg Fibre Uses:

3.6.1 Computer Networking and Broadcasting:

Due to optical fiber's capacity for high bandwidth and data transmission, computer networking is a typical fibre optics application case. The usage of fibre optics to improve connectivity and performance is also common in broadcasting and electronics.

3.6.2 Internet & Cable Television:

Internet and cable TV are the two applications where fibre optics is most widely employed. Fiber optics can be installed to provide long-distance communications between computer networks in disparate locations.

3.6.3 Under Sea Environments:

Due to their ability to be immersed in water and the fact that they don't require regular replacement, fibre optics are employed in conditions that are more dangerous, such as underwater cables.

3.6.4 Military and Space:

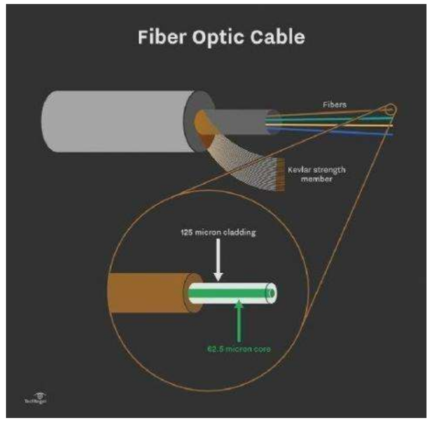
In addition to its capacity to sense temperature, optical fibre is also used in the military and space sectors as a signal transmission and communication medium. The reduced weight and smaller size of fibre optic cables can be advantageous.

3.6.5 Medical:

In a number of medical tools, fibre optics are routinely employed to give accurate lighting. It also makes it possible for biomedical sensors to be used more often in less invasive medical treatments. It is suitable for various tests like MRI scans since optical fibre is not susceptible to electromagnetic interference. X-ray imaging, endoscopy, light treatment, and surgical microscopy are among further medical uses for fibre optics.

4. How Fiber Optics Works:

In fibre optics, data is sent as photons or light pulses that move across a fibre optic connection. Due to the different refractive indices of the glass fibre core and cladding, incoming light is bent at a certain angle. Light signals travelling via fibre optic cable bounce repeatedly off the core and cladding using a phenomenon called total internal reflection. Light signals move around 30% slower than light because to the denser glass layers, which prohibit them from travelling at the speed of light.



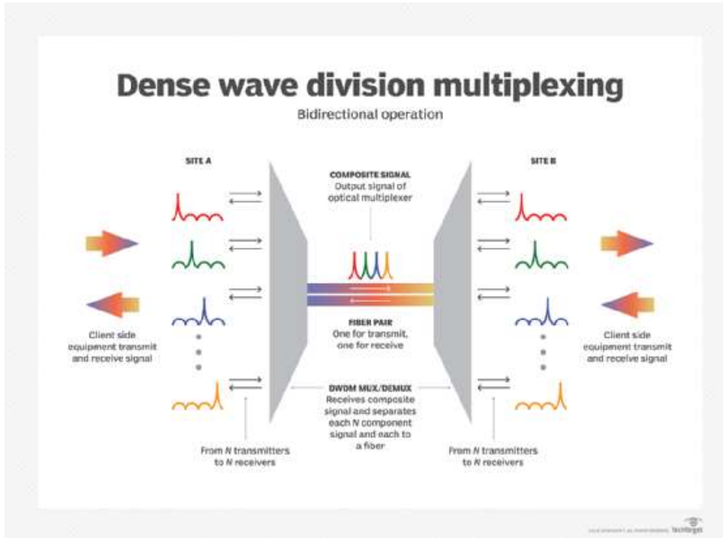
Fiber optic transmission sometimes needs repeaters at a distance to refresh, or amplify, the signal throughout its path these repeaters refresh the optical signal by converting the optical signal to an electrical signal, processing that electrical signal, and then retransmitting the optical signal. Up to 10 Gbps transmissions may currently be supported by fibre optic connections. A fibre optic cable often gets more costly as its bandwidth capacity increases.

4.1 Fiber Optic Cable Types:
Multimode fiber and single-mode fiber are the two primary types of fiber optic cable.

4.2 Single-Mode Fiber:
Single-mode fibre is used for greater distances since the glass fibre core has a smaller diameter. The smaller diameter lessens the possibility of attenuation, or a weakening of the signal. The light is concentrated into a single beam by the smaller aperture, giving the signal a more direct path and expanding its range.

A lot more bandwidth is available with single-mode fibre than with multimode fibre. For single-mode fibre, a laser is often used as the light source. Since precise calculations are needed to create the laser light in a tiny hole, single-mode fibre can occasionally be more costly.

4.3 Multimode Fiber:
Given that light signals can bounce and reflect more along the path due to the larger core aperture, multimode fibre is used for shorter distances. The larger diameter makes it feasible to send more data across the wire at once by allowing for simultaneous transmission of multiple light pulses. But as a result, the probability of signal loss, reduction, or interference is raised. In multimode fibre optic connections, an LED typically generates the light pulse.



Existing fibre networks can have their capacity increased using dense wavelength-division multiplexing (DWDM)

4.4 Special Purpose Fiber:

Some non-cylindrical core or cladding layers, often with an oval or rectangular cross-section, are used in the construction of special-purpose optical fibres. These include fibre that keeps sensors' polarisation in check and fibre designed to stop whispering gallery mode propagation.

Photonic crystal fibres have an identifiable pattern of index variation as cylindrical holes. By employing diffraction effects in place of or in addition to perfect internal reflection, such a fibre limits light to its core. The properties of the fibre allow for a variety of applications.

4.5 Comparison between Fiber Optics & Copper Cables:

For many years, copper wire cables were the standard option for cable connections in telecommunications, networking, and other areas. However, fibre optics eventually gained popularity as a substitute. Fiber optic cables currently make up the majority of long-distance telephone lines. Optical fibre has a higher bandwidth and faster speeds than traditional copper cable, which allows it to transmit information more efficiently. Fiber optics is not susceptible to electromagnetic interference, and signal losses are kept to a minimum since glass doesn't conduct electricity.

5. Fabrication Methods:

Incorporating periodic variation into the fiber's core is the focus of this section. The periodic variation might be etched either inside or outside. But inside, it is neither helpful nor practical (internal writing and Holographic Technique).

The multiple externally scribed techniques, such as the Interferometric Technique, Phase Mask Technique, and the Point by Point approach, will get beyond the limitations brought on by the internal techniques.

5.1 Interferometric Technique:

Melt gave the first example of it. The fibres can be written using either an amplitude splitting interferometer or a wave front splitting interferometer using this method. While wave front splitting interferometers use a slit from which a wave front emerges and is separated before being forced to interfere with each other, amplitude splitting interferometers use a partial reflector to split the beam into two beams before they interact again [14]. The fundamental advantage of amplitude splitting interferometric approaches is that bragg gratings may be produced at any desired wavelength. However, it is quite susceptible to mechanical vibrations. A powerful laser with great spatial and temporal coherence is also required for this method, unlike the Phase Mask Approach. One optical component is all that is needed for a wavefront splitting interferometer, lessening its susceptibility to mechanical vibrations. This is its main benefit. However, this approach has drawbacks such as grating length limitations and lack of Bragg wavelength tunability [15].

5.2 Phase Mask Technique:

It is one of the methods for making FBGs that is most often used. An optical diffraction grating device called a phase mask is used to spatially regulate the UV writing beam [16].
A beam is diffracted into several orders with m = 0, 1, 2, and 3 when it hits the phase mask. Where the transmitted beam is indicated by m = 0 [17].

The interference of beams of different orders results in a fringe pattern that permanently shifts the refractive index of the fibre core, etching the Bragg grating onto optical fibres. The fringe period halves the phase masking periodicity in half. Even though there are other orders of beams, m = +1 or m = 1 is frequently the only order employed to build the gratings. Additional 884 T. Kori et al. modes must be suppressed in order to generate a stronger interference pattern [18]. The application of a phase mask simplifies the production of FBG.

Fibre is so near to the phase mask, the sensitivity to mechanical vibrations is considerably decreased, as are the stability issues. Poor temporal coherence lasers have no effect on writing capabilities, however low spatial coherence lasers do. Furthermore, due to the fiber's placement, the fibre may come into contact with the phase mask, causing damage to the tiny grating corrugations.

6. Applications:

In the communication system, optical communication is a well-known technique. Light is employed to send the signal to the receiver instead of electric current. Signals are sent to the receiver end of optical communications via optical fibres. The usage of Fiber Bragg Gratings (FBG), which is fully examined in the sections above, is one such application. Modern technical developments have been significantly facilitated by optical communications.

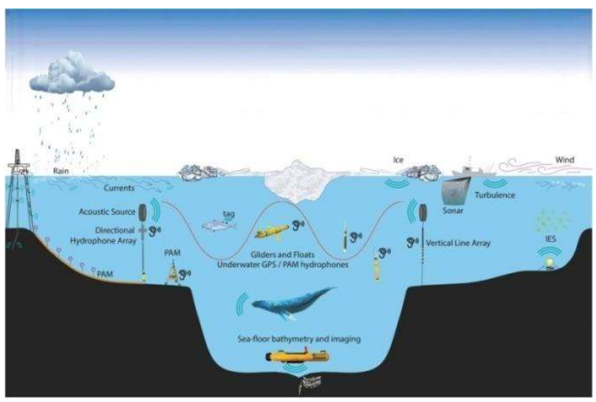
6.1 System for Monitoring the Structural Health of Aircraft:

To improve the safety and dependability of the aircraft, a health monitoring system is used. Utilizing multi-sensor data integration technology, it detects systemic failure. Intensity-based, interferometric, distributed, and grating-based fibre optical sensors used to monitor strain in aircraft composition are divided into these categories [19]. Fiber Bragg Grating sensors are excellent for monitoring a wide range of sensor properties since they are simple to install on any surface. They are affordable as well as made of composite materials [20, 21].

It may be utilised in many different aviation applications, such as Unmanned Aerial Vehicles and Micro Aerial Vehicles, to monitor the health of aerial vehicles and forecast both their security and system performance [22].

6.2 Underwater Acoustics Sensor:

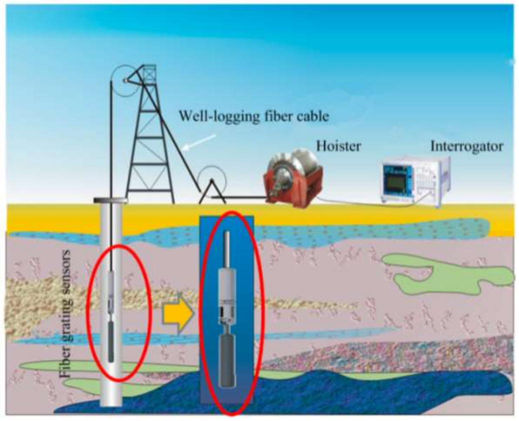
Reginald Fessenden invented the hydrophone in 1949 to detect underwater noise. When the external landscape changes, a hydrophone turns the sound wave into an electric signal. Underwater Sounds is another title for a hydrophone. The water might be from the ocean, the sea, leks, a pool, or even a tank. Operating at frequencies between 10 Hz and 1 MHz, this device. Below 10 Hz, it is hard for sound to disperse in water without penetrating deep below the ocean floor; similarly, frequencies beyond 1 MHz are less likely to be used since they are quickly absorbed.



One of the main benefits of FBG is that they can survive damage to front-end optical fibres. It takes use of reflection with a narrow wavelength bandwidth, which helps with multipoint sensing or several measurements being taken at once [23]. When there is sound, a pair of paired FBGs send laser light through them and reflect it back, adjusting the strength of the laser light. According to the theoretical prediction, the FBG submerged acoustic sensor's output is proportional to the applied sound pressure [24].

6.3 Oil and Gas Industry:

The oil and gas industry is the world's largest. Petroleum is the principal raw ingredient for a wide range of chemical goods, including fertilisers, polymers, skin care products, and many more.



Fiber Bragg Grating Used in Oil and Gas Industry:

This sector of the economy is expanding quickly, which raises the yield and profit margin and necessitates technological know-how for efficient production in the fields of reservoir exploration and oil-well production management.

Numerous studies have been conducted on Fiber Bragg Grating and its uses in the oil sector, particularly in the area of well logging. In seismic research, FBG sensors are employed to measure pressure, temperature, and other physical characteristics in an unexplored environment [25]. The frequency range of 5-2.5 Hz, which conveys essential geological information, requires high sensitivity from FBG sensors for this application. Due to its small size, light weight, flexibility, superior temperature resistance, and immunity to electromagnetic interference, fibre optic sensors are chosen over piezoelectric ones. Fiber optics are favoured over all other types of sensors as a consequence [26].

7. Conclusion:

A succinct research on fibre bragg grating and bragg fibre offers crucial information on its workings, kinds including uniform, chirped, blazed, and superstructure grating, as well as many insights on how light may be steered in various configurations depending on the application utilisation and propagation. The manufacture of bragg gratings using various methods is explored, showing how system stability is raised while mechanical vibration susceptibility is reduced. In order to demonstrate how fibre bragg gratings improve applications' efficiency, sensitivity, lightness, and cost-effectiveness when compared to traditional sensors, three significant applications in upcoming technologies are examined. Although more study has to be conducted on a wide range of applications to provide the finest goods that handle socioeconomic concerns of future trends.

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