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Detection of Atmospheric Water Vapor Using Lidar Techniques

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Abstract

Water vapor is the main objective in cloud formation, hydrological cycle and radiative balance of the atmosphere. So detection of water vapor is important for the remote sensing and weather forecasting. The objective of this analysis is to design and analyze the fibre based DIAL (Differential absorption LIDAR)system for the measurement of atmospheric water vapor. The analysis is basically to find the suitable fibre for this application. Also designing the theoretical parameter of the fibre of choice and analysing with the commercially available fibres.

Keywords: Atmospheric water vapor, LIDAR systems, Numerical Aperture Spot size.

Introduction:

Water vapor is the Earth's important green house gas, accounting for 90% of the natural green house effect, which helps to keep the Earth warm enough to support life. Human activities do not directly increase the content of water vapor in the atmosphere however hot air can contain more water vapor than cold air. Therefore, human activities that increases the temperature of atmosphere near the ground will cause more water to evaporate. Warmer, the surface greater the evaporation of water from the surface. As a result, increased evaporation leads to the greater concentration of water vapor in the atmosphere. Over 99% of atmospheric moisture is in the form of water vapor, and this vapor is the principle sourceof atmospheric energy that drives the development of weather systems on short time scale and influences climate on long time scale. We have incorporated DIAL technique to detect the presence of atmospheric water vapor. LIDAR is light detection and ranging in the remote sensing technology which measures the distance between the source and target by illuminating the target with the laser and analysing the reflected light. LIDAR equation is given as follows.

$$I_r(R,\lambda) = I_0\eta\frac{A}{4\pi R^2}\beta(R,\lambda)\exp\left(-2\int_0^R\sigma(R,\lambda)dr\right) \quad (1)$$

Where,
A is area of the receiver, η is the system optical efficiency, R is the distance between source and target, I_0 is the incident photon count, I_r is the received photon count, β(R,λ) is backscattered coefficient, σ(R,λ) is extinction coefficient.
Fibre based LIDAR systems bridges a gap between large scale high peak LIDAR systems and miniature LIDAR systems.

Methodology:

We have incorporated LIDAR technique to measure atmospheric water vapor. The block diagram of the system is as follows.

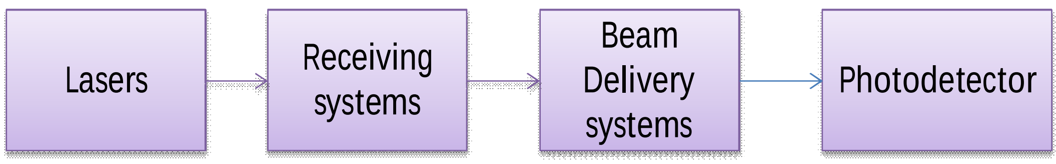

Figure 1: Block Diagram of The Detection System

Lasers:
Lasers is a device that emits through a process of optical amplification based on stimulated emission ofradiation. Stimulated emission is a process by which incoming photons interacts with the atomic electrons at a particular frequency and drops to a lower energy level.

$$E_2 - E_1 = h\nu_0 \quad (2)$$

Where,
E2 is higher energy level, E1 is lower energy level.The photon will have frequency ν and energy ν_0 where h is Planck constant.

Receiving Systems Consists of A Thin LensAnd Multiplexer:
Parallel rays of light near the axis of lens meet at a point called principle of focus of lens the distance from the centre of the lens to the principle focus defines focal length of the lens. Focal length is positive for converging lens. Thin lens is the one in which thickness of the lens is small compared to the focal length.The equation is given by .

$$\frac{1}{F} = \frac{1}{d_0} + \frac{1}{d_i} \quad (3)$$

Where d_0 is the distance betweenthe objects and length, d_i is the distance between the lens and image, F is the focal length.
Multiplexer is a device that selects one of the input wavelength signal and forward the selected input wavelength into a single line. Multiplexer is cost effective because it combines multiple input into a single data stream.

Beam Delivery Systems:
Multimode fibre is a optical fibre that is designed to carry multiple light rays or modes concurrently each at the different refraction angle within the optical fibre core.It is used for relatively short distances because the mode tendsto disperse over longer lens. Usage of Multimode fibres makes the system compact.

Resultsand Discussions:
Acceptance angle is the half of the angular aperture of the optical fibreand acceptance angle can be calculated by the following formula.

$$\theta = \tan^{-1}\frac{radiusofthelens}{focallength} \quad (4)$$

According to our analysis, having lens diameter as 18mm and focal length as 20mm, we get acceptance angle as 24.228°.
Numerical Apertureis the range of angles over which the system can accept or emit light. NA can be calculated by thebelow formula.

$$NA = n\sin\theta \quad (5)$$

Where n is refractive index of air,θ is the acceptance angle.Having the acceptance angle as 24.228° and n=1 (in the air) and substituting in the above equationwe get Numerical Aperture as 0.41036.
The focal length of a lens determines the magnification at which it images the distant object. Following formula can be used to calculate the focal length of the lens

$$\frac{1}{F} = \frac{1}{d_0} + \frac{1}{d_i}$$

Having $d_0 = 40\,mm$ and $d_i = 40\,mm$ and calculating the focal length we get F=20mm.Formula to calculate the core diameter.

$$S = \frac{4\pi}{\lambda} * \frac{F}{D} \quad (6)$$

Where,F is the focal length, D is the diameter of laser beam, λ is the wavelength.Substituting the values of the obtained parameter we get Spot size as 93.5598µm.

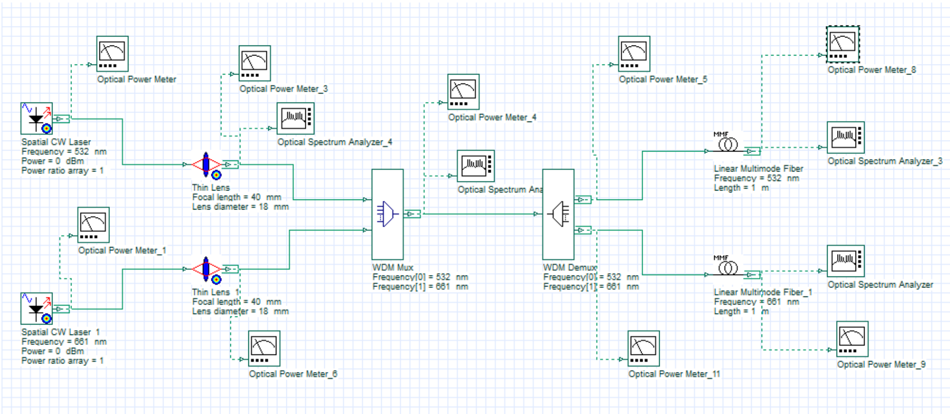

Figure 2: Circuit diagram of DIAL

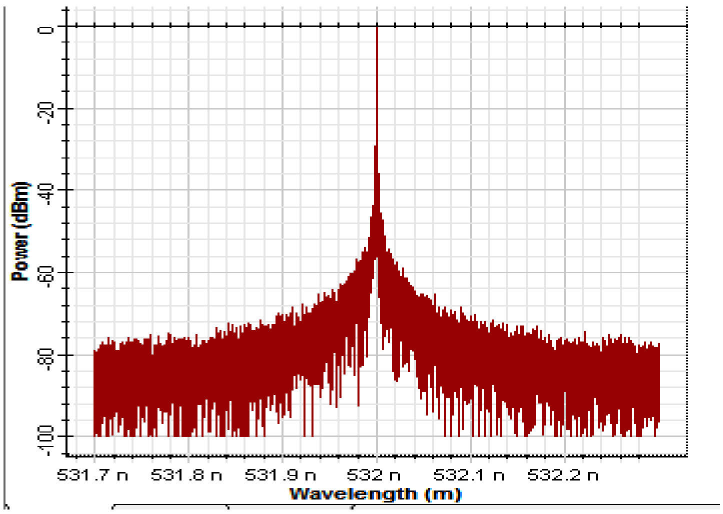

Figure 3: Input spectrum of CW laser

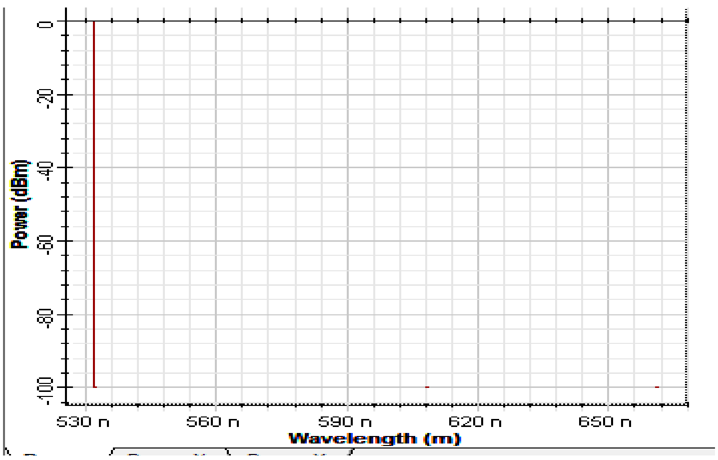

Figure 4: Output Spectrum of The Lens

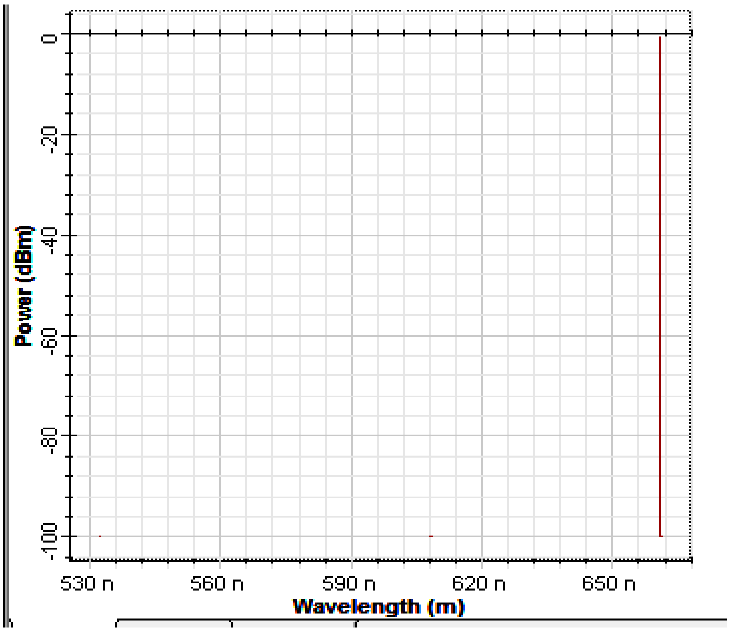

Figure 5: Detection of the Atmospheric Water vapor

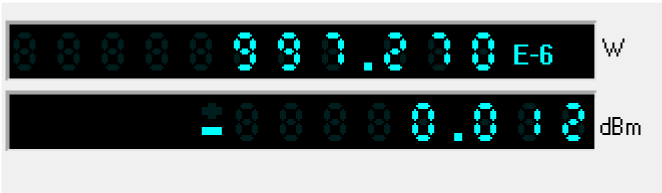

Figure 6: Measured Output Power

Conclusion

From our analysis we have found that numerical aperture is 0.41036, acceptance angle as , focal length as 20mm and spot size as 93.5598µm and we analysed that if we use 0.48 NA low or high OH having 100µm as core diameter multimode optical fibre practically we can get the maximum efficiency when compared to other fibres.A new compact, efficient, and light weight water vapor measuring DIAL system has been constructed to measure the atmospheric water vapor profile from Earth surface. The fibre is pumped by 532nm CW laser and the obtained backscattered rays is incident on the concave lens. A low mass receiver was constructed to detect the atmospheric backscatter return. such a Lidar would then be used at multiple Earth's locations to accurately measure the Water vapor profile for improved weather prediction.

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