International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 2
February 2018

Design of Compact Aerosol Particle Sensor by Integrated Spectropolarimeter using III-V-on-silicon Photonic Integrated Circuits

Sandeep Battula[1], Aleti Krishna Chandra Mouli[2], Suresh Jaka[3]
Department of Electronics and Communication engineering
Aditya Institute of Technology and Management, Tekkali

Abstract—Aerosols are minute particles suspended in the atmosphere. When these particles are sufficiently large, we notice their presence as they scatter and absorb sunlight. Their scattering of sunlight can reduce visibility (haze) and redden sunrises and sunsets. The atmospheric lifetime of 0.1 to 1 micrometer particles is thus very strongly linked to hydrological cycle. These accumulation mode aerosols are those which penetrate most deeply into the lungs of human beings and causing severe health hazards. Particulate monitoring is a gap in the current technology as it doesn't provide sensitivity, longevity and it has a poor calibration. This is because spectroscopic analysis of aerosol measurements is largely affected by the atmospheric extinctions. Specifically, this proposal addresses this issue by introducing integrated spectropolarimeteric technique (polarization spectrum is normalized to the value at a certain arbitrary wavelength, e.g.600nm) using InP-based type II DFB laser heterogeneously integrated on a III-V-on silicon waveguide. Because earth's atmosphere doesn't affect the polarization state of incident radiation, high precision spectropolarimetry is much easier than spectrometer or photometer.

Keywords—spectropolarimeter,photonic integrated circuits, III-V-on –silicon waveguide, InP-based type II DFB laser.

I. INTRODUCTION

The question of efficient measurement of aerosol particles in the atmosphere has been a debate among the environmentalists. Because spectroscopic analysis alone doesn't provide efficient information about the properties of aerosol particles because atmospheric extinctions effects the observing conditions. Besides, polarimetry alone doesn't provide accurate measurements of aerosol properties because of the fact that comparison of multiple spectra of any particulates is not straight forward, even spectra appear totally different. In principle, the observed differences might due either to the fact that the spectra were obtained at different phase angles or to differences in the surface structure of aerosols. So we introduce a new concept for measurement and is known as 'spectropolarimeter' i.e. the polarization spectrum is normalized to the value out a certain arbitrary wavelength e.g.600nm. But the instrumentation to be used for this purpose is not compact. In the view of portability, we would go for silicon photonic integrated circuits. Photonic Integrated circuits occupied a major role in the field of photonics. Several optical instruments have been integrated on silicon waveguides and transformed larger optical equipment portable. These advantages finds the silicon photonic integrated circuits in the areas like gas sensing, bio sensing, finding size distributions of certain micro particles. For optical instrument integration, III-v-on- silicon photonic integrated circuit is being employed. The paper is organized as follows. Section II introduces how spectropolarimetric observations can be accomplished mathematically with some graphical curves. The third section focuses on heterogeneously integrated III-V laser sources and photodectors. The fourth section provides the integration of polarizers with III-V laser sources to get the output of spectropolarimeter on the silicon waveguides. Finally section five introduces Brownian motion and how it can be eliminated by incorporating neural networks.

II. SPECTROPOLARIMETRY

Polarization depends on the wavelength gives useful constraints to the modelling of particulate matter. For polydisperse, dust particles, multicolor polarimetry and spectropolarimetry are also promising tools for better characterization. The reason for opting spectropolarimetry can be best explained by considering polarization spectra of asteroid aerosol atmosphere at different phase angles as shown in figure(1). The left panel of fig.1 shows the polarization spectra of various asteroids of different taxonomic classes obtained at different phase angles. Their comparison is not straight forward, even when spectra appear totally different (like, e.g., in the case of Pallas and Eros). This is just because, the observed spectra has been made at different phase angles or may due to the differences in the surface structure of asteroids.

Spectropolarimeter takes this problem and efficiently normalizes the polarization spectrum to an arbitrary wavelength. The right panel in the fig.1 shows the normalized polarization spectrum. Under the hypothesis that at first order the polarization spectra may be expressed as the product of two functions, one that depends only on the phase angle and on that depends only on the wavelength, $P_r(\lambda,\alpha)=p'(\lambda).A(\alpha)$, then the normalized polarization spectrum.

$$p(\lambda) = \frac{P_r(\lambda,\alpha)}{P_r(\lambda=600nm,\alpha)} = \frac{p'(\lambda).A(\alpha)}{p'(\lambda=600nm).A(\alpha)}$$

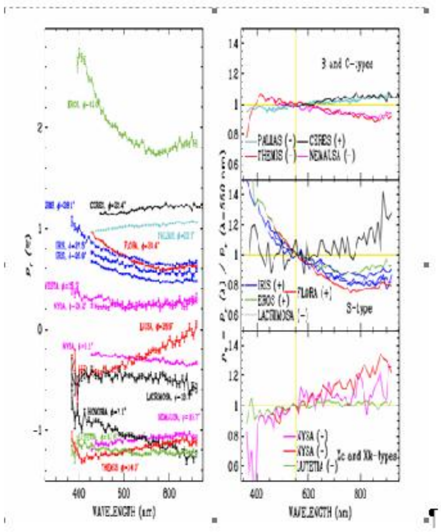


Fig.1. Left panel: Polarization spectra of asteroids observed at different phase angle. Right panel: normalized polarization spectra for a target sub-sample. (Eur.Phy.J.Plus (2017) 132:105)

The results thus obtained with multicolor polarimetry by Lupishko and Kiselev [5] and Belskava et al.[24]. Bagnulo et al.[25] have shown that P_Q spectra of low-albedo surface have a positive gradient, and P_Q spectra of intermediate-albedo always shows negative gradient. In case of high-albedo, multiple scattering can reach higher orders of scattering and thus, depolarization of light by multiple scattering is stronger. Therefore, we expect that if the reflectance spectrum of an atmosphere increases with wavelength, then the absolute value of polarization decreases with wavelength. So, finally we can conclude that in spectroscopy, the choice of solar analogue used for the intensity spectra and the quality of the calibration of the atmospheric extinction may sometimes effect the reflectance spectra. By contrast spectropolarimetry measurements are independent of atmospheric conditions, and do not require any calibration. These techniques still allow us to obtain simultaneously also reflectance spectra provided that the usual calibrations are performed, therefore they can nicely complement traditional spectrophotometric techniques. But in order to implement this technology, we need to install bigger equipment's in order to find the aerosol properties. In attempt to have a portable device, our choice has picked up silicon photonic integrated circuits. In the next section we will accommodate the optical instruments on a III-V-laser sources and photodectors.

III. III-V-ON-SILICON PLATFORM

In this section we will first introduce how we can implement spectrometer on silicon photonic integrated circuit using III-V-on-chip silicon and mid infra-red InP-based type II DFB heterogeneous laser integrated on silicon waveguides along with photodectors. Combining a mid-infrared DFB laser array with AWG spectrometer allows coupling of light from different lasers to a single diffraction limited output waveguide with low loss. Secondly, Polarizers made of hydrogenated amorphous silicon claddings were deposited on each branch of a splitter. Combination of polarizers with DFB laser system results in spectropolarimeter and will be discussed in next section.

A. *Mid-infrared silicon photonic integrated circuits*

In many cases, the spectroscopic sensing system should have a light source, a probe component and a spectrometer. For a compact sensor system, both

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 2
February 2018

light source and a detector should be integrated together with the waveguide. Figure 2 shows the typical configurations of fully integrated mid-infrared on-chip spectroscopic sensor. The probe component in one arm interacts with the environment while the other one provides the reference information. For liquid sensing, a low-cost broadband light source such as light emitting diode (LED) can be used since liquid samples typically have broad absorption features. In this, a spectrometer with integrated photodetectors should be used to analyze the absorption spectra. For Aerosol sensing, typically a tunable single mode laser is required to probe the absorption lines of gases(aerosols), as used in the popular tunable diode lasers absorption spectroscopy(TDLAS) technique. By integrating a widely tunable laser or a broadband wavelength coverage laser array on the wavelength circuit enables to simultaneously detect several gases or even broad absorption features of liquids using the configuration as shown in the figure.

Generally we would like to send the aerosols through an inlet provided in between tunable laser source and a beam splitter. The laser light then will be scattered by these aerosol particles.

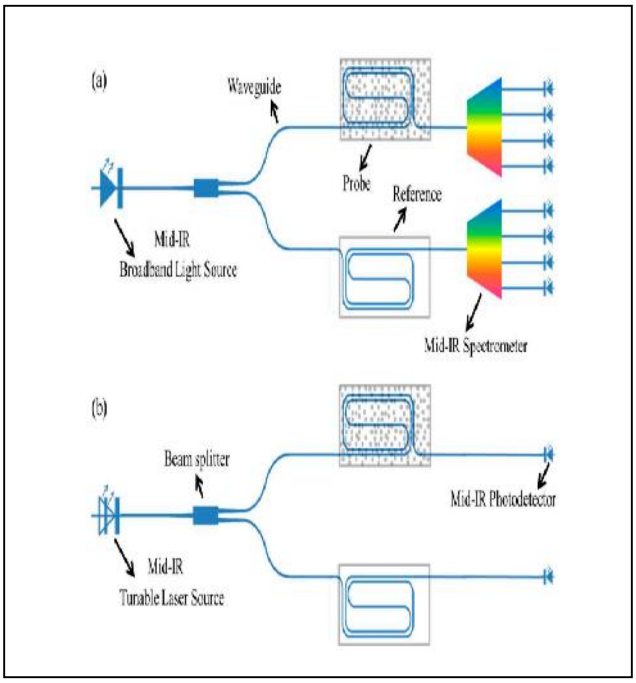


Fig.2. (a) Integrated on-chip mid-infrared absorption spectroscopy sensor. (b) Tunable single mode laser source for aerosol detection. Image courtesy (Sensors 2017,17,1788;doi:10.3390/s17081788)

B. Integrated Disrtibuted Feedback Lasers and Photodectors

Distributed feedback (FBD) lasers are well-suited for TDLAS measurements of aerosols. Figure 3 shows schematic of an InP-based type II DFB laser heterogeneously integrated on a silicon waveguide. The device is divided into two parts: a gain section, most of the optical mode is confined in the III-V

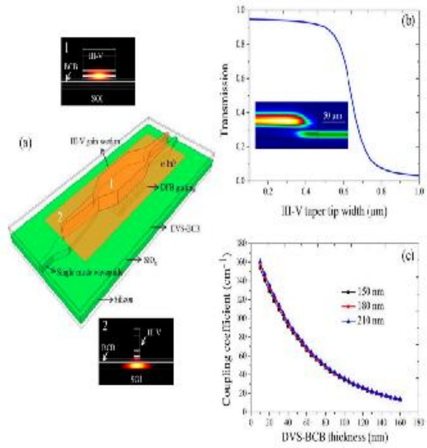


Fig.3.(a)schematic of an InP-based type DFB laser integrated on silicon waveguide; Image courtesy (Sensors 2017,17,1788;doi:10.3390/s17081788)

wave guide. The III-V waveguide is linearly tapered from 5 micrometer to 1.2 micrometer over the length of 50 micrometer. In the second section, the III-V waveguide is slowly tapered to a narrow tip while the silicon waveguide is tapered to 0.2 to 3 micrometer over the length of 180 micrometer. The limited tuning range of a DFB laser limits the number of gases detected with the source. The development of broadly tunable laser sources enables multi-species or polydisperse aerosol particles.

B. III-V-on silicon photodectors

Besides light sources, photodetectors also be integrated on the photonic integrated circuits as it plays a major role in spectroscopic sensing. These photodetectors are to be placed on epitaxial layer stack as the heterogeneously integrated InP-based type-II DFB laser. Figure 3(a) shows the schematic diagram of this photodetector. The III-V mesa of photodetector is a 150 micrometer long waveguide, tapered from 1 micrometer to 3.5 micrometer. In this way, the light is coupled from silicon waveguide to

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 2
February 2018

III-V waveguide by a narrow taper tip, and it is observed by the active region. The other III-V photodetector is based on the grating-assisted coupling as shown in fig.3.(c).

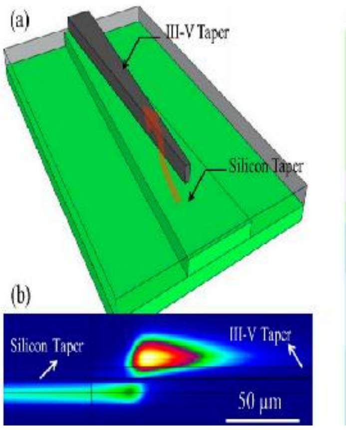
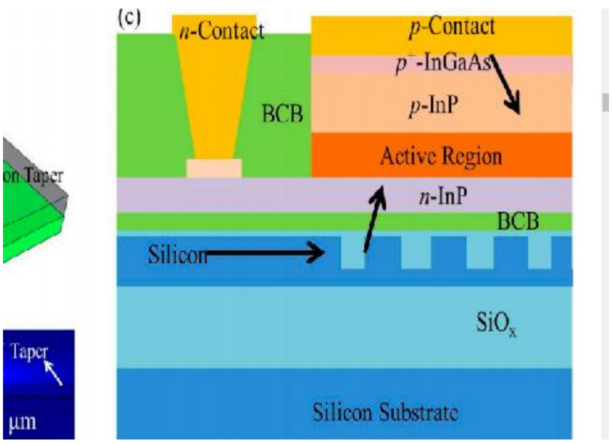


Fig.3. (a) schematic of adiabatically-coupled photodetector; (b) mode intensity distribution in a longitudinal cross section. (Sensors 2017,17,1788;doi:10.3390/s17081788)

IV. INTEGRATION OF POLARIZERS ON III-V SPECTROMETRIC SYSYEM

Generally photonic integrated circuit consists of a Y-branch waveguide splitter like in the case we have seen previously while building a integrated



spectrometer formed by potassium sodium ion exchange in silicate glass. Hydrogenated amorphous silicon claddings were deposited on each branch of the splitter to act as a polarizer. The spectrum thus obtained from the spectrometer is given to this polarizer which consists of a cladding polarizer acts as a modulator and the detector at the end converts light signal to electric signal. Thus obtained polarization spectrum is normalized and spectropolarimetric observations can be done on aerosols in a compact and portable way. Figure 4 shows the schematic diagram of how polarizer claddings are placed on the Y-branch splitter.

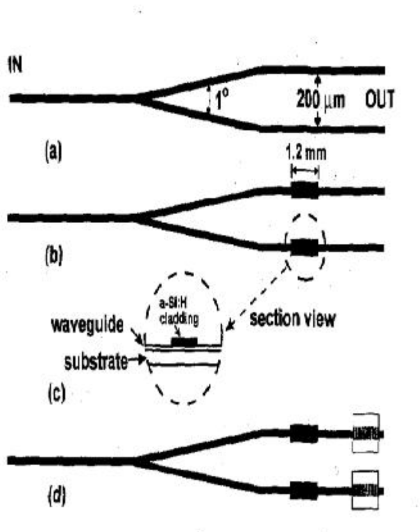
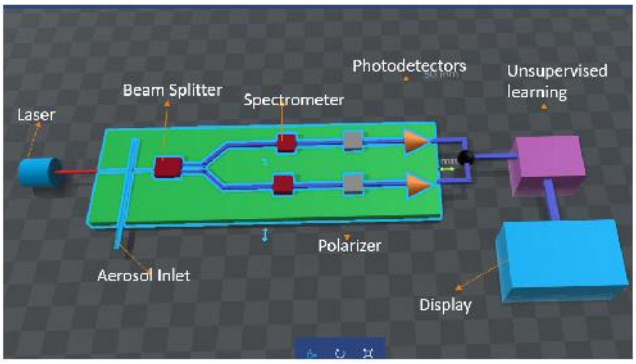


Fig.4. Structure of Y-branch device through various fabrication steps. (a) After masking and ion exchange. (b) After deposition and pattering of 1.2 mm a-Si:H polarizer claddings. Image courtesy (journal of lightwave technology, VOL.13,NO.11,November 1995)

V. *NEURAL NETWORKS*

When we want to measure any microscopic particles, a major thing to consider is that the Brownian motion. Because particles get collided with each other and the motion of them becomes random. This Brownian motion includes false measurements in the sensors readings. There has been a debate in this in the recent days. This can be efficiently overcome by introducing neural networks (Unsupervised learning) into the crease and the data from the spectropolarimeter is fed to the neural network. Thus we can provide an efficient measurements by eliminating these random walks.



VI. CONCLUSION

We have successfully theorized and demonstrated a use of spectropolarimeter over spectrometer and photometer alone and then introduced III-V-on chip silicon integrated circuits for detecting these aerosol particles. We have demonstrated a integrated spectrometer using InP-based type II DFB laser heterogeneous structure and then we demonstrated the integration of III-V –on silicon photodetectors and successfully implemented a laser spectrometer. And then we theorized the integration of polarimetry and spectrometer together to get spectropolarimeter.

Acknowledgment

The Authors wish to acknowledge the helpful technical assistance and advice of Pof.V.V.Nageswara Rao DR. M.N.V.S.S Santosh Kumar, M.Balakrishna, J. Suresh Kumar

References

[1] S.Bagnulo, I.Belskaya, A. Cellino, and L.Kolokolova "Polarimetry of small bodies and satellites of our solar system," Eur.Phys.J.Plus(2017),vol 132:105.

[2] David L. Veasey, and Donald R. Larson, "Integrated Optical Polarization-Discriminating Receiver in Glass", Journal of Lightwave Technology,Vol.13,No.11, November 1995.

[3] E.M.A. Frederix, A.K.Kuczaj, M.Nordlund, M.Belka, F.Lizal, J.Jedelsky, J.elcner, M.Jicha, B.J.Geurts, "simulation of size-dependent aerosol deposition in a realistic model of the upper human airways" Journal of aerosol science 115(2018) 29-45