Enabling Photonics Technologies for Advanced Aerospace Sensors

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ABSTRACT

This paper overviews the various photonics technologies involved in aerospace sensor applications. The basic principle and applications of new emerging photonics technologies such as fiber optics, integrated optics, silicon photonics, MOEMS, photonic correlators, adaptive optics and focal plane arrays have been discussed briefly. Futuristic areas of research with respect to these technologies are also listed.

1. INTRODUCTION

This decade has been witnessing a rapid growth in Photonics research and technology owing to a large number of applications in civilian as well as in defence. The major applications of photonics in defence include sensing, surveillance, target detection & acquisition, command control communication & intelligence and electro-optic counter measures. Photonics technology based sensors have completely revolutionized the aerospace sensor requirements such as in missile tracking & command guidance, inertial sensors for navigation, imaging sensors etc. Some of the key enabling technologies in aerospace sensors are uncooled imaging technology, focal plane array technology, adaptive optics, fiber optics technology, Micro-Opto-Electro-Mechanical Systems (MOEMS), optical correlators etc. This paper highlights the development of some of these technologies for applications in aerospace sensors. In the subsequent sections we describe briefly about the photonics technologies involved in aerospace sensors.

2. PHOTONICS TECHNOLOGIES FOR AEROSPACE SENSORS

2.1 Fiber optic sensors

Another technology which finds a number of applications in aerospace sensors is fiber optics technology owing to lesser weight and electromagnetic immunity of optical fibers. For example, fiber optic gyro is used in the inertial navigation units of missiles. This works on the principle of phase difference between the two counter-propagating optical waves calibrated in terms of rotation.

Other type of sensors based on fiber optics technology are Fiber Bragg grating sensors which are also called smart sensors represent an exciting development in fiber-sensor technology. Fiber Bragg grating sensors can monitor the condition of an object in use by providing the real time feedback by reflecting different wavelengths depending on the condition of the object. These periodic series of gratings (refractive index modulations in the core of a single mode fiber) can be written by using an ultraviolet beam with the help of phase mask generates a low loss, highly reflective, wavelength sensitive filter system. This non-invasive process does not change the fiber’s strength, electromagnetic interference immunity or dielectric properties. Bragg grating sensors, when fabricated and annealed properly, have proven to be permanent, easily reproducible reflectors that can withstand very high temperatures an added advantage in case of aerospace applications. The Bragg gratings give response to changes in temperature, compression and strain by changing the reflected wavelengths. In addition, performance of these sensors does not depend on amplitude or intensity. The biggest advantage with these kinds of sensors is their small size and weight which enables them to be easily attached to a surface to provide information on the state of an object under scrutiny. As an example, in the case of guided missiles Bragg grating sensors can be used for monitoring structural condition during test flight of a missile.

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2.2 Integrated Optics Technology

This is a sophisticated technology which has been an active area of research for the last two decades. A multifunction integrated optical chip (MIOC), based on this technology, is an integral component of a Fiber optic gyroscope which is used in inertial navigation system. This is used to compensate for the phase difference between the two counter-propagating beams that is introduced due to the rotation of the system. MIOC includes 3-dB splitter, polarizer and a phase modulator onto a single chip. Lithium Niobate ($LiNbO_3$) are used for making MIOC owing to its excellent electro optic properties.

2.3 Silicon Photonics

Silicon photonics refers to the integration of optical components such as lasers, waveguides, modulators etc. onto a single Silicon chip which can be manufactured using standard semiconductor equipments. This area has been researched upon world over since 1980s due it smaller weight, low volume, lesser cost and easy availability of silicon material. Silicon photonics, in general, consists of six basic building blocks viz. an inexpensive light source, devices that route, split, and direct light on the silicon chip, a modulator to encode or modulate data into the optical signal, a photo detector to convert the optical signal back into electrical bits, low-cost, high-volume assembly methods and supporting electronics for intelligence and photonics control. This technology finds wide variety of applications in communication, computing, sensors and detection. For example, it has been used in trans-receiver modules in communications, optical bus systems, amplifiers etc.

2.4 Micro-Opto-Electro-Mechanical Systems (MOEMS)

These systems represent another exciting development particularly, for missile and space applications. The advantages related to the light weight, smaller volume and low power requirements have a great impact on the applications such as the terminally guided sub-munitions. Micro mirrors based on this technology are the crucial enabling technology for these systems. Due to these advantages, design and fabrication of MOEMS are the focus of current research efforts.

2.5 Optical Correlators

Optical correlator works on the principle of Fourier transform property of a lens and a hologram of a fourier transform of an object as viewed from a particular perspective, to establish a matching correlation coefficient. Optical correlators can be effectively used for automatic target recognition, missile guidance and tracking of the target scenes which do not have prominent features or high contrast with the background. The speed and innate parallel processing capability of optics enable the correlator to simultaneously recognize and locate all objects in a scene almost instantaneously. These systems are very important for the missile guidance applications, specially the midcourse and terminal guidance of long range surface to surface missiles.

2.6 Adaptive Optics technology

Adaptive optics systems are used to improve the image quality by reducing the phase aberrations introduced when an optical wave travel through the atmosphere. In other words, this system compensates for the turbulence induced phase distortions of optical waves propagating through the atmosphere. Adaptive optic systems typically consist of a wavefront phase sensor, focusing optics, a spatial light modulator (SLM) for correcting phase errors, imaging sensors and the control and processing electronics. Adaptive optic system has been an active area of research which finds enormous application in the field of guided missiles. Now the research has reached to a stage that these systems could be made lightweight, consume low power and compact. The technologies such as highly integrated low power electronics and new processing architectures for error sensing and control, flexible high density packaging, Micro-Opto-Electro-Mechanical Systems etc. are making this possible in practical.

2.7 Focal plane array technology

Focal plane array technology is an important technology for missile seekers and other imaging sensors. The focus of research has been mainly devoted to developing larger size arrays, higher resolution and higher sensitivity focal planes. The current research is also focused on reducing the pixel size and increasing pixel sensitivity using advanced materials and micro electromechanical device structures. The advancement in FPA technology has a direct impact on the guided missile systems. For example, target detection and lock on range of a guided missile can be significantly increased by enhancing the performance of the FPA.

3. THRUST AREAS OF R&D

Having discussed some of the key technologies in the preceding sections, it is important to list some of the key research areas which have attracted the attention of the researchers world over. These areas are subdivided into the following subsections:

3.1 Photonic Devices

(a) Optical amplifiers
(b) Optical Correlators
(c) Lithium Niobate, Gallium Arsenide and Silicon based integrated optical components for example, high speed modulators, all-optical switches, wavelength division multiplexers (WDM) etc.
(d) All-optical logic circuits
(e) Optical pattern recognition.

3.2 Photonic Materials

(a) Laser materials such as Nd: YAG, Nd:YVO_4, Nd:YLF, Er:YAG, Ti Sapphire, Nd Glass etc.
(b) Non-linear materials for frequency conversion such as Lithium Niobate, Periodically poled Lithium Niobate (PPLN), KTP, Periodically poled KTP (PPKTP), BBO, LBO etc.
(c) Semiconductor materials such as Silicon, GaAs, CdTe, CdZnTe, etc.
(d) ZnS, ZnSe and Chalcogenide glasses for IR optical components.

3.3 Photonics Technologies

(a) Diode pumped solid state lasers (DPSS) for pump sources
(b) Optical parametric oscillator for frequency conversion, for example for tunable laser sources
(c) Erbium doped fiber amplifiers (EDFA) for all fiber amplification for communication.
(d) Real-time optical processing
(e) Integrated optics for waveguide fabrication
(f) Holographic optical elements (HOEs)
(g) Periodic poling of materials such as Lithium Niobate, KTP, GaAs etc.

3.4 Sensors

(a) IR sensors
(b) Thermal imagers
(c) Fibre Bragg grating based sensors,
(d) Fibre Optic gyroscopes (FOG)

4. CONCLUSION

To conclude, photonic technologies will play a dominant role in futuristic aerospace sensor systems. In fact, photonic devices have been designed, fabricated and demonstrated for use in next generation high performance tactical avionics.

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