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ADVANCEMENT IN PHOTONICS FOR SPACE COMMUNICATION

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Abstract: Photonic technologies have changed the world of communications in the form of fiber optics, integrated optics, electro-optical components, and micro-photonics. They offer some compelling advantages compared with their traditional RF counterparts when considered for use in space applications. Thus, research and development of photonics technologies for the space, the applications in areas of communications, sensing, and signal processing has been a major them for several years. The use of the photonic technologies for the space applications has risen the problem related to ability of optoelectronic and optic components to withstand space environment as all optoelectronic and optic components come from the terrestrial applications. Thus, the development of photonic technologies for the space applications has made the selection and acceptance test criteria of all optoelectronic and optic components that are part of the photonic system imperative. This presents a summary of the experience to Alter Technology Group on the mechanical, thermal, radiation, and endurance testing of several photonics technologies. In addition, the paper describes an assessment relates to reliability of these parts to be usefull in the space applications.

I. INTRODUCTION

The selection and evaluation procedures of COTS optoelectronic components for the use in space application need to be established because there is no qualified components exist and also there are no standards that are available that define the procedures to be applied for optoelectronic device to be used in space qualifications. The following paragraphs propose a generic procedure for the selection and acceptance test criteria for optoelectronic devices and also include an analysis related to the Specification Performance.

The use of photonic technologies in the space applications has risen the problem related to ability of optoelectronic and optic components to withstand the space environment as all optoelectronic and optic components come from terrestrial applications. The photon is a type of the elementary particle, the quantum of electromagnetic field including the electromagnetic radiation such as light waves, radio waves, and the force carrier to the electromagnetic force (even when static via virtual particles). The invariant mass of the photon is zero it always moves at the speed of the light within a vacuum. Like all elementary particles, photons are currently best explained by the quantum mechanics and it exhibit wave-particle nature.For example, a single photon may be has been refracted by a lens and exhibit wave interference with itself, and it can behave as a particle with a definite and finite measurable position or momentum, though not both at the same time as per the Heisenberg's uncertainty principle.

II LASERS IN PHOTONICS

The first successful use of the laser for a space experiment was registered on 9 May 1962, as it's a part of the Laser Lunar Ranging experiment. Since the laser device is located on the Earth's surface, it did not need to be fullfill the additional specifications required for the space flights, such as mechanical stability, thermal shocks, thermal light and radiation resistance.

The first diode-pumped solid-state laser (DPSSL) to be sent into space was been delivered in 1992 and launched as part of the Mars Orbiter Laser Altimeter (MOLA) in the year of 1996, the laser used an Nd: YAG crystal as a active medium [2]. The use of semiconductor laser technology in the space was reported to a direct laser application rather than pumping, when the world's first laser-based optical data linkconnected to the Artemis satellite from the ESA with the Centre National d'Études Spatiales (CNES) Earth observation satellite SPOT 4, using GaAlAs laser diodes emitting at 0.8µm. It is also the worth highlighting the first laser pulse emitted on the planet surface other than Earth on 19 August 2019, by laser integrated in ChemCam device installed on Curiosity Mars rover, which used an Nd: KGW crystal DPSSL.Fig 1shows the constraints associated with the laser operation in the space are different from those in the terrestrial applications. Thus, the lasers suitable for the space applications need to present specifications, such that it has long lifetime, high efficiency, low susceptibility to optical misalignment contamination, and unattended operation, among others. The best laser has to be selected depending on requirements of the applications and environment.

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Figure 1: Optics

III SEMICONDUCTOR LASERS

Semiconductor laser has been studied and used for years in the space applications. Some of the main advantages include operation under direct current injection, which provides the high electrical to optical power conversion efficiency, but also it has a long lifetime and high output power. Although their divergence, beam quality,and the intensity noise are not suitable for all the applications, they are also preferred pump element for the solid- state lasers (SSLs) and fibre lasers since their wavelength can be slightly tuned to achieve the optimum absorption of the laser media, making them the cornerstone for the laser technologies used in space applications. Many materials are being used, such as GaAs, InGaAs, InP, and InGaAsP. The two most common types of semiconductor laser are the edge-emitting laser (EEL) and the vertical-cavity surface emitting laser (VCSEL).In the diode laser, the amplifying element is the forward-biased PN junction formed in a direct-bandgap semiconductor. Optical gain is provided by recombination of electrons and the holes in the PN junction. Whenforward biased, electrons are injected from N side while holes are injected from the P side; both electrons and holes are confined within the lower bandgap region where they can recombine either in the spontaneously or viastimulated emission when excited by an existing photon. Operating voltage has been determined by bandgap of emitted light plus a linear factor caused by the series resistance, for 1-µm radiation, the operating voltage is of around 2 V. Diode lasers is extremely efficient. For example, recent progress on “wallplug” efficiency (i.e.,conversion of electrical input power to the optical output power) of diode lasers operating in 940-nm wavelength range is approaching nearly 70 percent. To the optical designer, the beam appears to be ideal point source, however, anamorphic because the divergences in the two perpendicular directions are very different.In addition, many single-spatial-mode lasers are slightly astigmatic, with the values ranging from the fraction of a micron up to the several tens of microns, depending on specific laser structure.

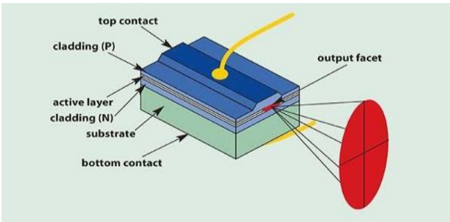

Figure 2: semiconductor Laser

III EDGE EMITTING LASER

EELs are most common semiconductor laser devices. Thanks to their diode junction structure, these devices can transform electrical energy into light. Apart from the SSL pumping, they are mostly suited to the applications, such as information relay (inter and intra satellite), matter light interaction (spectroscopy and pyrotechnics), planetary exploration and monitoring, metrology, and the sensors Some direct applications for which they are being used which includes, for instance, the autofocus system of the ChemCam laser or rendezvoussensor for docking of the European Automatic Transfer Vehicle to the International Space Station (ISS) EEL have already been deployed in the satellites, in the deep space, and also on Martian surface.In semiconductor lasers, a distinction is made between the surface-emitting and edge-emitting lasers. In surface-emitting lasers, the laser light is emitted perpendicular to wafer surface, and in edge-emitting lasers (EEL),the laser light propagates along the wafer surface and is coupled out at a chip edge.In order for the EEL laser to achieve the necessary light amplification, the resonator cavity must have a length between a few hundred micrometers and a few millimeters. The length of the resonator cavity determines the beam focusing of the EEL laser. The light beam itself has an elliptical shape, which must be focused by optics into a round light beam as shown in Fig 1.4. Edge-emitting lasers include the DFB laser, and surface-emitting lasers include the VCSEL laser. Edge-emitting lasers can emit light powers ranging from the few hundred milliwatts with highbeam quality to up to 100 W with low beam

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quality, depending on the diagonal structure. They are used in laser pointers, CD players and in optical transmission technology[5].

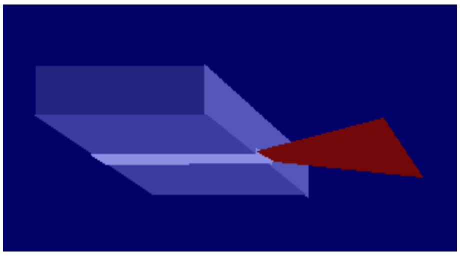

Figure 3: Edge Emitting Laser

IV SOLID STATE LASER

Most of the SSLs that we will discuss are pumped by the semiconductor diode lasers (DPSSL). In Figure 3 presentsSSL present several advantages over the semiconductor laser, such as beam quality and possibility to allow for extra versatility by reaching wavelengths and the output powers which are not easily achieved by the semiconductor lasers. In addition to this, short pulses can be emitted, for instance, through Q-switching, which are commonly used in the range-finding applications. The space applications in which DPSSL lasers are used it includesLight Detection and Ranging (LIDAR) and spectrometer devices [8]. An example of the former application would be GEDI (Global Ecosystems Dynamics Investigation Lidar) instrument, developed by NASA's Earth Venture Instrument (EVI) space program, which uses version of the High Output Maximum EfficiencyResonator (HOMER) laser, an Nd:YAG crystal side-pumped by the seven, 4-bar G-package laser diode arrays. An example of latter application would be ESA/ROSCOSMOS ExoMars 2020 mission to Mars, that includes a Raman Laser Spectrometer (RLS) instrument whose excitation source is an intracavity frequency-doubled DPSSL emitting at the range of 532 nm, pumped by a CW (continuous-wave) Q-mount diode emitting at the range of 808 nm.Some of the early studies were directed towards the short pulses of neutrons exciting the upper isomer state in the solid so the gamma-ray transition could benefit from the line-narrowing .It was conjectured thatthe nucleus of an atom, embedded in near field of a laser-driven coherently-oscillating electron cloud would experience the larger dipole field than that of the driving laser. Furthermore, nonlinearity of oscillating cloud would produce the both spatial and temporal harmonics, so the nuclear transitions of higher multipolarity could also be driven at the multiples of the laser frequency. Solid-state lasers are being developed as optional weapons for F-35 Lightning II, and are reaching near-operational status, as well as introduction of Northrop Grumman's FIRESTRIKE laser weapon system.

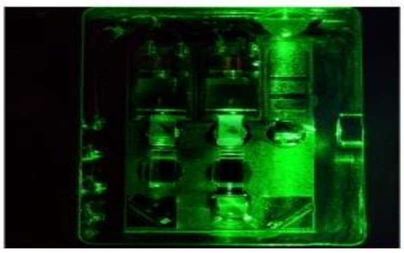

Figure 5: DPPSS green laser

V ADVANTAGES

1. Earth Observation: Observing Earth from space can provide the better perspective, additional information, and a more global vision to the study of planet.
2. Spectroscopy: passive and active spectroscopy are useful in a wide range of the scientific and industrial applications, but also in the space applications.
3. Using light waves instead of electrical wires for microprocessor communication functions couldeliminate the limitations now faced by conventional microprocessors.
4. Using light has the potential to be brutally energy efficient.
5. Single fiber-optic strand can carry a thousand different wavelengths of light at the same time, allowingfor multiple communications to be carried simultaneously in a small space and eliminating cross talk.
6. Almost limitless bandwidth and propagation to the longer distances.
7. Intra-Satellite Communication and Inter-Satellite Communication.

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VI APPLICATIONS

1. Telecommunication: optical down-converter to the microwave, and optical fiber communication.
2. Medical applications: laser surgery, poor eyesight correction, tattoo removal and surgical endoscopy.
3. Manufacturing processes in industries: involves the use of laser in welding, cutting, drilling, and many surface modification techniques.
4. Building and construction: smart structures, laser range finding, and laser levelling.
5. Space exploration and aviation: including astronomical telescopes.
6. Intra-Satellite Communication and Inter-Satellite Communication.
7. Digital Communication Links.
8. Analogue Communication Links.

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VII CONCLUSION

Very few of the optical components are qualified forspace applications. This means that optics are necessary most of times .A cost-effective approach for selection and acceptance criteria of these has been presented in this topic. Detailed construction analysis, endurance, radiation and the environmental test performed before the completequalification flow can be very useful for increasing the reliability of devices and reducing both priceof the selection and project qualification. It is recommended to do this prior to any project qualification activity.Specific test setup conditions must be considered when working with photonics parts to ensure test bench is suitable to provide electro-optical characteristics while parts are being submitted to environmental test in operating conditions.

VIII FUTURE SCOPE

1. It can be used for the opto pyrotechnics in Propulsion which is Indirect Ignition System by the Detonation ofPyrotechnics Using the Short Laser Pulses.
2. Integrated Solid-State Gyroscopes.
3. Solar System Targets.
4. The development of the fibre optics technology for telecommunications can result in the new devices, including novel optical sources.
5. Fibre Optic Sensing.

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