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# A Review Study of Some Optical Characteristics of Superluminescent light Emitting Diode

Hassan Absalan
Department of physics, Ahar Branch, Islamic Azad University, Ahar, Iran
Email: absalanh@gmail.com
Review Article

## Abstract

*In this paper, some optical characteristics of superluminescent light emitting diode (SLED) have been studied. The output power of SLED has been described by assuming a uniform carrier density distribution and zero reflection from the faces. In SLEDs, the total optical power depends on the drive current and the output intensity, does not exhibit a sharp threshold. Typical values for SLED modules are for the optical bandwidth between 5 nm and 100 nm with central wavelengths covering the range between 400 nm and 1700 nm. The structure and the material composition used for the SLED chip affect the gain.*

**Keywords**: superluminescent light emitting diode (SLED), output power, optical gain, spectral ripple, polarization

## 1. Introduction

Over the last few years, the semiconductors of group III-nitride and their triple compounds have been remarkable as a promising element in electronics. This materials are considered as an ideal candidate for applications in the field of optoelectronic devices such as light emitting diodes (LEDs) used in solid-state lighting and high-density optical storage systems due to their wide band gap. A superluminescent light emitting diode (SLED) is an edge-emitting semiconductor light source that combines the high power and brightness of laser diodes (LDs) with the low coherence of conventional LEDs. Its emission optical bandwidth, also described as full-width at half maximum (FWHM). This light source was developed as a key component in the next generations of fiber optic gyroscopes, low coherence tomography for medical imaging, and external cavity tunable lasers with applications to fiber-optic communications [1,2].Similar to a LD, a SLED is based on an electrically driven p-n junction that, when biased in forward direction, becomes optically active and generates amplified spontaneous emission (ASE) over a wide range of wavelengths. The peak wavelength and the intensity of the SLED depend on the active material composition and on the injection current level. SLEDs are designed to have high single pass amplification for the spontaneous emission generated along the waveguide but, unlike LDs, insufficient feedback to achieve lasing action. This is obtained very successfully through the joint action of a tilted waveguide and anti-reflection coated (ARC) facets.

Fig. 1 shows schematic view of a SLED [3]. This diode includes regions of quantum well (QW), barriers, separate confinement heterostructure (SCH) layers and coating layer. In the active region of this diode, QWs produce the light and the SCH layers and the coating layer play the role of confinement and waveguide of light, respectively. Also, SLED is an optical source with wide optical bandwidth. This feature is seen as a low temporal coherence.

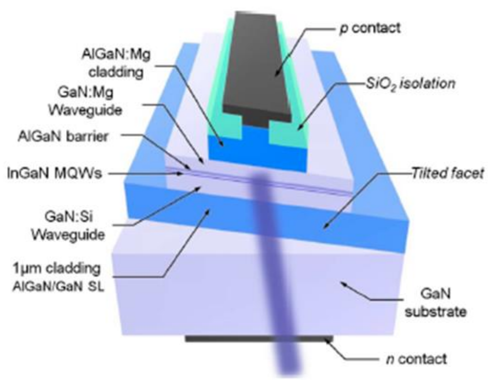


**Fig. 1.** Schematic view of a SLED [3].

The structure of SLED can be homogeneous or inhomogeneous. In a homogeneous structure, both sides of the junction are made of the same semiconductor material, and in an inhomogeneous structure, the two sides of the junction are made of different materials. The inhomogeneous structure is divided into two categories: the structure with a single heterojunction (SH), which includes one inhomogeneous junction, and the structure with a double heterojunction (DH), which includes two inhomogeneous junctions. The structures of the second type can have a bulk active layer, single quantum well (SQW) or multiple quantum wells (MQW). Most of the produced SLEDs are based on GaAs and InP. The first SLED based on GaN with an active region of InGaN MQWs, operated under pulsed current, was developed in 2009 [3].

## 2. Principles of Operation of SLED

When an electrical forward voltage is applied, an injected current is generated from one side of the active SLED region (p-side) to the other side (n-side) [4]. The electric current flows from p to the n portion and across the active region that sandwiched between the two p and n sections. During this process, light is created due to the spontaneous and random recombination of positive (hols) and negative (electrons) carriers, and then amplified by moving along the waveguide of a SLED. The p-n connection of semiconductor material of a SLED is designed in such a way that electrons and holes can obtain a number of possible energy bands of different energies. Thus, the recombination of electrons and holes creates a light with a wide range of optical frequencies.

SLEDs that work in wavelengths between 1300 and 1400 nm are mainly based on a bulk material that has low polarization gain. Also, for the operation of devices in the range of 1400 to 1600 nm, the active region of a QW with strong polarization gain is used. Therefore, the optical field emitted by the SLEDs, which is a combination of non-polar spontaneous emission and amplified radiation, has a certain degree of polarization.

In view of the above, with the optimized optical cavity design, SLEDs have high output power, wide bandwidth and residual low spectral ripple [5]. These features make SLED as an ideal light source for a wide range of applications. According to the requirements and specifications, SLEDs are available with a wide range of wavelengths and powers. SLED devices based on InP operate in the high wavelength range (1100 to 1700 nm). SLEDs based on GaAs also operate in wavelength range between 630 and 1100 nm. In addition, SLEDs based on GaN are used in ultraviolet and blue spectral range.

### 3. Main Characteristics

The optical output power emitted by the SLED is dependent on the ASE rate and the optical gain [3]. It can be improved by increasing the injection current, decreasing the density of defects, increasing the electron-hole recombination rate, decreasing the compressive strain and quantum confined stark effect (QCSE), and improving the crystalline quality in the active region of the MQWs. The output power performance of an ideal SLED can be described with a simple model, not taking spectral effects into account and considering both a uniform distribution of carrier densities and zero reflections from the facets [6]:

$$P_{out} = \frac{h}{c}.\nu.\Pi.R_{sp}\,\frac{\exp[(g-\alpha)L]-1}{g-\alpha} \qquad (1)$$

where is the Planck constant, the optical frequency, the size of the optical mode, the spontaneous emission rate into the guided mode, the modal gain, the non-resonant optical losses, the length of the active channel and the velocity of light. According to this, the output power depends linearly on the spontaneous emission (SE) rate and exponentially on the optical gain. Obviously a high modal gain is required to obtain high optical output power.

The optical gain is usually defined as the fractional increase in photons per unit length and in quantifying the gain. We need to know the number of transitions that will occur per second in the device in response to a given flux of photons in a given optical mode. The optical gain is calculated as [7]:

$$g(E) = \frac{\pi\hbar}{nE}\frac{e^2}{m_0^{\,2}\varepsilon_0 c}\left[1-\exp\left(\frac{E-\Delta f}{k_B T}\right)\right] \times \sum_{n_c, n_v} \frac{|M|^2}{4\pi^2 L_w} f_c f_v \frac{1}{\pi}\frac{\frac{\hbar}{\tau}}{(E_{eh}-E)^2+\left(\frac{\hbar}{\tau}\right)^2}\, dk_x\, dk_y \qquad (2)$$

where $\Delta f$ is the quasi-Fermi level separation and dependent on carrier density, $E$ is the photon energy, $k_B$ is Boltzmann constant, $T$ is the temperature, $m_0$ is the electron effective mass in the free-space, $e$ is the electron charge, $\varepsilon_0$ is the free-space dielectric constant, $n$ is the refractive index, $c$ is the light velocity, $|M|^2$ is the squared optical transition matrix element of momentum for transition between the hole subbands ($n_v$) and the electron subbands ($n_c$), $f_c$ and $f_v$ are the Fermi–Dirac distributions for electrons in the conduction bands and holes in the valence subbands, respectively, and are given by

$$f_v = \frac{1}{1+\exp[\frac{(E_{n_v} - E_{f_v})}{k_B T}]} \tag{3}$$

$$f_c = \frac{1}{1+\exp[\frac{(E_{n_c} - E_{f_c})}{k_B T}]} \tag{4}$$

where and are the quantized electron and hole energy levels, respectively.

The total optical power emitted by SLED depends on the drive current. Fig.2 shows the dependence of optical power on injection current for a SLED [6]. Unlike LDs, the output intensity does not exhibit a sharp threshold but it gradually increases with current. A soft knee in the power versus current curve defines a transition between a regime dominated by spontaneous emission (SE) and one that is dominated by ASE. It should be noted that if the output power is affected by SE, the amplification mechanism affects the polarization state of the emitted radiation.

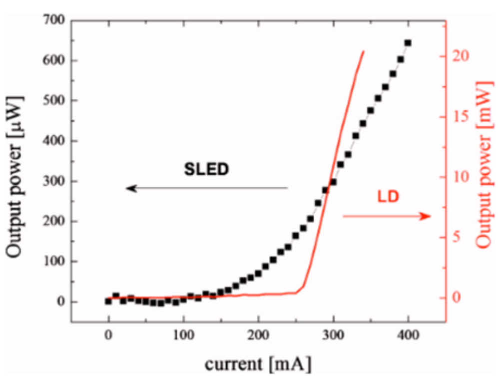


**Fig. 2.** Dependence of optical power on injection current in a SLED [6].

The dependence of the optical power density on the wavelength for a SLED can be seen in Fig. 3. The optical power emitted by SLEDs is distributed over a wide spectral range. Two useful parameters that are related to the power density distribution at different wavelengths are the optical bandwidth (BW) and the peak wavelength ($\lambda_{peak}$). The first is defined as the FWHM of the power density versus wavelength curve at the nominal operating conditions while the latter corresponds to the wavelength having the highest intensity. The centre wavelength, is defined as the central point between the two FWHM points of the spectral curve; it can be different from the peak wavelength since it is related to the spectrum asymmetry.

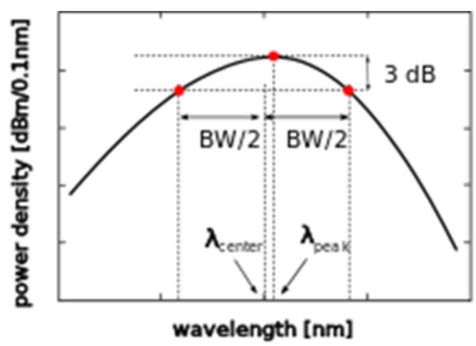


**Fig. 3.** Dependence of the optical power density on the wavelength for a SLED.

The spectral ripple is the measure of the variation of the spectral power-density that can be observed for small change of the wavelength. It can be detected using high-resolution optical spectrum analyzers and can be ascribed to the residual reflectivity of the chip facets and of the coupling fiber. Spectral ripple is more evident in high-power devices and mainly around the peak wavelength where the device gain is higher. It is always present to some extent but undesirable since it has strong effects on the coherence properties of SLED. The spectral ripple at maximum output power can be seen in Fig. 4.

Some SLEDs from certain manufacturers exhibit an extremely low value of the ripple even at the highest power levels. An excessive level of optical back-reflection can cause unexpected irregularities of the spectral distribution of SLEDs that have not to be confused with the ripple. During operation it is therefore important to carefully limit the feedback from any additional equipment.

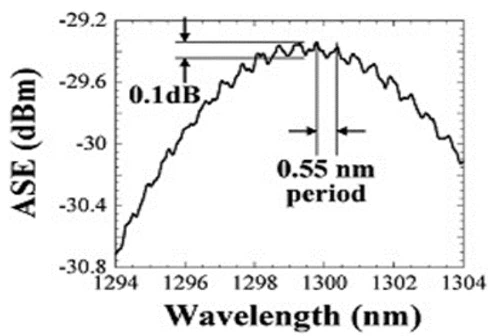


**Fig. 4.** Spectral ripple at maximum output power.

The structure and the material composition used for the SLED affect the gain that the radiation experience during the propagation and lead to different amplification factors for different orientations of the electric field (polarization dependent gain). SLEDs operating in the wavelength range of 1300 and 1400 nm are mostly based on a bulk material and a chip structure both characterized by a low polarization dependence of the gain. On the contrary, devices operating in the 1550 and 1620 nm range make mostly use of a QW active region that has a strong polarization-dependent gain. The optical field emitted by the SLED chips, being a combination of unpolarized spontaneous emission and amplified radiation, has therefore a certain degree of polarization.

The optical power emitted by semiconductor active devices is always affected by fluctuations (intensity noise) that are induced by the spontaneous emission. When the emitted power is detected with a wide-bandwidth square-law detector the intensity noise will be converted into current fluctuations and the measured photocurrent will include a constant term, $I_0$, proportional to the mean optical intensity and a time dependent term, $I_n$, related to the intensity fluctuations.

The spectral distribution of the noise term in the photocurrent can be measured by means of an electrical spectrum analyzer over a radio frequency (RF) range that is limited by the electrical bandwidth of the detector used. The resultant noise spectrum is directly related to the optical intensity noise and in general depends on the RF frequency. From this measurement a useful parameter that provides quantitative information on the noise of the optical source can be evaluated. It is the relative intensity noise (RIN), that is the ratio between the power spectral density of the noise current and the square value of the average photocurrent,

$$RIN(\omega) = \frac{\langle I_n^{\,2}(\omega) \rangle}{\langle I_0^{\,2} \rangle} \tag{5}$$

The RIN therefore represents the ratio between the noise power and the average power after detection. The measurement unit used is the dB/Hz. Typical values measured for SLEDs depend on the injection current (more correctly on the output power) and on the RF frequency range. Intensity modulation of SLEDs can be easily achieved through direct modulation of the bias current. SLED modules do not include terminating resistors inside because, operating at relatively high currents, excessive cooling would be required to compensate for the heat dissipation of the resistor.

As mentioned earlier, SLEDs are optical sources with a rather wide optical bandwidth. In that they differ from both lasers that have a very narrow spectrum and white light sources that exhibit a much larger spectral width. This characteristic mainly reflects itself in a low temporal coherence of the source. SLEDs may however exhibit a high degree of spatial coherence, meaning that they can be efficiently coupled into single-mode optical fibers. Some applications take advantage of the low temporal coherence of SLEDs sources to achieve high spatial resolution in imaging techniques. The coherence length, $L_C$ , is a quantity frequently used to characterize the temporal coherence of the light source. It is related to the path difference between the two arms of an optical interferometer over which the light wave is still capable to generate an interference pattern. For sources having a Gaussian spectral distribution, the value of the coherence length is inversely proportional to the spectral width, BW,

$$L_C = \frac{\lambda^2}{BW} \tag{6}$$

where  is the central wavelength of the emitted radiation. As an example, an SLED operating around 1300 nm and with an optical bandwidth of 100 nm is expected to have a coherence length of about 17 μm.

## Conclusion

Some characteristics of superluminescence light emitting diode were studied. The light power emitted by the SLED depends on the drive current. The maximum current that allows safe operation of the device varies between 70 mA and 500 mA. Spectral ripples can be detected using high-resolution optical spectrum analyzers and can be attributed to the residual reflection from the chip surfaces and the coupling fiber. Polarization extinction ratio is the ratio between maximum and minimum intensity measured after a rotating linear polarization.

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