Design and simulation of semiconductor laser with GaAs active region

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Abstract

In this paper, we focus on designing and simulation of a gallium arsenide semiconductor laser with an active zone. We've used aluminum gallium arsenide material in the sides with the mole fraction of 0.5 (Al$_{0.5}$Ga$_{0.5}$As). For simulation we have used the SILVACO software of ATLAS simulator environment. First, we review a structure similar to the laser and then to achieve proper optical confinement and carrier confinement, we use several structures to design the laser. Simulation results show that the laser emits photons at a wavelength of 0.87 micrometers. The obtained results indicate that laser shows its proper performance in IR light.

Keywords: laser, cavity, semiconductor, active region.

1. Introduction

The word laser is derived from Light Amplification by Stimulated Emission of Radiation phrase. Albert Einstein in 1917 in an article entitled "The Quantum Theory of Radiation" explained the initial invention of the laser method. There are different types of lasers classified based on mechanism of stimulation, number of stimulation levels, the output wavelength, input and output energy, output power, etc. Currently we are able to manufacture lasers almost in every wavelength, including infrared laser, ultraviolet and X-ray lasers. Following we examined the review of previous works. Using of semiconductor lasers should be significantly expanded to function in the communication system [3]. In 2013, Hans Wenzel worked on design and simulation of a high power semiconductor lasers. In this paper, mostly formulation and relations related to lasers have been studied [4]. Articles and other works that also have worked on the dynamic relations of lasers designing can be found in [6, 8]. Modern simulation of semiconductor lasers requires that we use numerical methods and complex physical models in 2D and 3D [10]. Lasers can be also constructing by other elements such as photonic crystal (PBC) [9]. Lasers can be designed and simulated according to the quantum laws and phenomena. One of these lasers is quantum dot laser which is capable of a good performance [5, 7]. In the field of designing and simulation of laser, it can also be referred to the following articles [1, 2].

2. The semiconductor laser

Lasers meantime working simply, have many applications, including medical, photography, mapping, communication and understanding of fundamental particles, etc. In 1917, Einstein was able to express spontaneous and stimulated emission of laser operation by explaining the process of atomic absorption. A laser can be examined through gaseous, solid and semiconductor state. The light which is created in gaseous and solid state lasers is a single wavelength and is much better than in semiconductor lasers. In the solid and gaseous state, created pulses are not controllable, but in the semiconductor laser, they can be controlled with flow. Power of semiconductor lasers is lower than solid and gaseous state, but controlled. Gas and solid lasers feature discrete wave,
however, semiconductor lasers mostly feature continuous wave. In telecommunications industries, mostly semiconductor lasers are used, therefore we also discuss designing and simulation of semiconductor lasers. The structure of a semiconductor laser includes 3 following parts:

- The carrier pump source or electron
- An environment with high utilization (active zone)
- Mirrors which are optical resonator.

In order that lasing operation occurs, 2 following requirements must be met:

- The number or density of carriers in the active zone must be high, so that population inversion occurs; to do so electron flow injection, inserted via the pump must be greater than threshold limits.
- Casualties of photons which are generated in the active zone must be less than their reinforcements, to do so we use a cavity.

The cavity is usually made from 2 mirrors which these mirrors do 3 following tasks:

- Cause positive feedback (e.g., the constant light reinforcing).
- Assign light radiation direction (Lights which are radiated in the directions other than these mirrors will be removed, but lights which are in the direction of these mirrors will be strengthen or directed).
- Determine the wavelength (depending on how far is the distance between mirrors, the wavelength is selected).

A Lasers cavity is formed as follows:

![Figure 1: The laser cavity](image)

L or cavity length must be selected according to Brag reflection relationship. In the selection of proper material for lasers must consider required accuracy. In the similar lasers, we have not good carrier confinement and optical confinement, because in these lasers materials are from the same type and feature same refractive index and only in the active region which we have accumulated carriers, the refractive index changes gradually; Therefore cannot provide the appropriate confinement. The following figure shows this state.
Based on above figure it can be seen that losses in similar laser is high, because the refractive index changes gradually. To solve this problem we use a laser in the several structures state. In this case since materials differ from each other, therefore refractive index will change in steps and provides a better confinement. Figure 3 shows this case.
When we use a several structure laser, since we have a good carrier confinement and optical confinement, therefore threshold flow is reduced and optical losses are decreased; this leads to increasing optical efficiency of laser.

3. The semiconductor laser structure

To simulate the laser we use ATLAS software. Simulation process of the laser is done step by step and as follow. In order to examine the optical equations and relations in laser structure, laser structure must be meshed. SILVACO software can solve equations in any mesh, therefore the smaller the mesh is, the obtained results which shows are more precise, but must consider this point that small mesh could cause a very long time of program execution. In the laser Simulation, active region is very important, because light is created in this area, therefore we select mesh of this area smaller than the rest in order to solved equations with greater precision. Figure 4 shows the meshed structure of the laser.

![Figure 4: meshed structure of semiconductor laser](image)

Here we select laser materials GaAs and AlGaAs with X = 0.5. Figure 5 shows this state.

![Figure 5: The materials used in simulations of laser](image)

Here we select aluminum gallium arsenide as the material for laser’s active zone.
4. Simulation results

Following results are obtained by applying bias to laser structure of. Figure 6 shows the intended threshold flow for laser operation.

In the LED we did not have flow threshold but for laser, threshold flow is argued. Before the laser performs light radiation operation, the output power is low. Therefore current injection must reach flow threshold so that lasing occurs. Before flow threshold, laser works in a LED mode since emission happens, but when flow exceeds the threshold, stimulated emission occurs and laser operation will be done. The Threshold flow is about 0.3 mA according to the figure. Figure (7) indicates the volt-ampere characteristic curve of laser. This variation curve indicates flow of laser in terms of voltage variations.

One of the most important curves in lasers and optical devices is output spectrum curve. This curve shows that in what frequency, the light is emitted. As shown in Figure (8) it can be seen that designed laser emits light at a wavelength close to 0.8698 micrometers. High wavelength is within infrared wave range. In the designed laser only one wavelength is amplified or in other words designed laser works in a single-wavelength mode. This suggests the proper functioning of laser.
The density of photons generated in terms of wavelength can be seen in the following figure. It is seen that in the functioning wavelength of laser, the amount of generated photons is proper.

Following suggestions can be also stated for continuing the work of other researchers:
1. Using other structures and materials in the design and simulation
2. Using the double structure to separate the optical confinement and carrier confinement

**Conclusion**

In this article, we discussed designing and simulation of a semiconductor laser and performed all stages of simulation in SILVACO applications in ATLAS software. In order to create proper optical and carrier confinements we used multi-structures for the laser designing. The obtained results show that the designed laser features proper flow threshold. Also optical power output spectrum of the laser is as single wavelength that also ensures the proper functioning of the laser. Designed Laser strengthens 0.8698 wavelength that is in the range of infrared waves. This Laser can be used in the communication applications such as SOA due to its single-wavelength feature.
References


