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Review Paper

Review on High-Efficiency External Cavity Diode Laser for Pr3+Doped Fiber

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ABSTRACT

Wide tunable range, narrow linewidth, and high resolution are the most demanded for industry, medical science, communication systems, optical coherence tomography, and spectroscopy analysis. External cavity diode laser (ECDL) has been the preferred scheme to realize for wide-tuning and narrow-linewidth characteristics. ECDL is advantageous in terms of low noise, high side-mode suppression ratio, high-temperature stability, simple structure, and low cost. Primarily, we will discuss different types of semiconductor lasers and different technique schemes for tuning. Then we will focus on the tunability of laser beams of semiconductor materials by using diffractive grating. Finally, the potential development prospects of wide tuning and high-output power diode lasers are presented and discussed.

Keywords: Semiconductor laser, Tunable, Narrow linewidth, diffractive grating.

1. INTRODUCTION

Semiconductor lasers, which offer incredibly affordable and small sizes, are growing in popularity daily. It has been in existence for more than 60 years and has seen significant change. Lasers were first developed as a single wavelength device without any obvious use, but today they are a widely used, multifaceted technology that supports many steps in the semiconductor production process. The two primary methods of producing semiconductor lasers are optically pumping the laser light and electrically pumping the current. Most lasers are powered by electricity. The selection of a particular light wavelength mostly influences the materials used in semiconductor design. Examples include GaN, InGaAs, AlGaAs, GaInP, InGaP, GaInNAs, and InP. Large band gaps characterize the infrared functions of AlGaAs, InGaAs, and GaInNAs. Currently, available GaN-based short wavelength lasers include GaInP, InP, GaN, InGaAs, GaInNAs, and AlGaAs. AlGaAs, InGaAs, and GaInNA function in the infrared spectrum and have large band gaps. Just now GaN (blue, red, and violet)-based short wavelength lasers with high beam power exceeding 1 W and excellent beam quality are widely used in spectroscopy and the medical field, among other applications. [1,], [2], [3].Commercially available GaN-based semiconductor lasers have an output power of a few watts [4], [5]. A watt class green and blue laser diode with an output power of 5 W for 3A current operating continuously wave was proposed by Murayama, M. et al. [6]. However, because of their large emission bandwidth and spectral bandwidth of approximately 1.0 nm, these high-power semiconductor devices are not as suitable for use in applications like holographic data storage, medical, laser cooling, optical coherence, and display imaging [7], [8], [9], [10], [11], [12].

Various methods have been used to attain big bandwidth, high power, and thin linewidth. Among them, enhancing the spectral linewidth of tunable systems primarily uses an external cavity diode laser (ECDL). It is simple to prepare and has excellent results. Here the basic principles of ECDL system are discussed and also presented research progress on this technology.

2. How Does ECDL work?

External cavity diode lasers (ECDLs) are diode lasers that produce narrow linewidth laser output that may be adjusted by using an external cavity with a diode laser chip. A diode, an external cavity, and feedback components are required for ECDLs. A partially reflected mirror is typically positioned at the diode's end to create the external cavity. Various methods have been used to attain big bandwidth, high power, and thin linewidth. Among them, enhancing the spectral linewidth of tunable systems primarily use an external cavity diode laser (ECDL). It is simple to prepare and has excellent results.

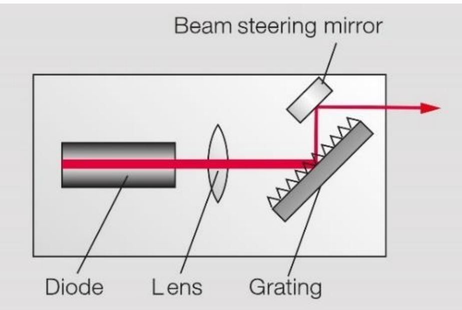

Fig.1: Schematic view of ECDL scheme

This type of simple structure helps incorporate the high efficiency of tunable wavelength with narrow linewidth. For ECDLs, the feedback element is used in two ways, 1-Littrow, and 2-Littman system.

2.1 Littrow Methodology:

The diffractive element is used in the Littrow technique so that the incident beam and the diffractive beam are the same. This indicates that the angles θ that the diffracted beam typically the first-order beam will propagate back along the incident beam.

$$n\lambda = 2d\sin\theta \dots (1)$$

where n is the number of orders (n=1 for the first order), μ is the diffracted angle, d is the grove distance, and λ is the operating wavelength. The output is the 0th order of feedback elements. With inefficient gratings, this especially easy-to-use and efficient configuration can be used to lower feedback and raise output power, improving overall efficiency [12], [10], [5]. The output beam in this system varies in direction in tandem with wavelength changes. These are the Littrow configuration's drawbacks. Nonetheless, because the mirror and the laser are oriented in the same direction, the laser's angle remains constant. The schematic view of the Littrow configuration is given as

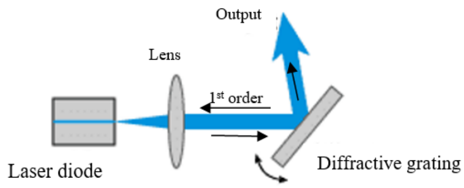

Fig. 2: A schematic view of Littrow configuration the ECDL system

2.2 Littman Methodology:

To reflect the diffractive beam's first order, there is an additional reflective mirror in the Littman configuration. Reflecting the first order to the grating is the reflective mirror's purpose. This indicates that the first order is reflected by the reflective mirror in this system, and the grating rotation is fixed. As a result, the coherent length is long and the 0th order's direction remains constant across wavelength changes. In this instance, the mirror angle determines the wavelength, keeping the grating and the zeroth-order reflected output beam fixed at that wavelength [13]. Due to this, the 0th-order efficiency is lost by tuning the reflective mirror. So, the power of the 0^{th} order is lower compared to the Littrow configuration.

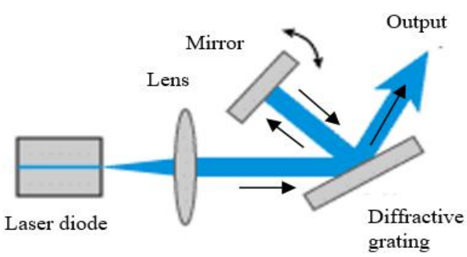

Fig.3: Schematic view of Littman configuration of ECDL system

3 Research Progress on ECDL's by Using Diode Laser

Nakamura et al [12] first demonstrated a GaN diode laser as a lasing medium with a peak wavelength of 445 nm with a linewidth of 1.6 nm. R.S. Conroy et al., characterized an extended cavity violet diode laser of 305 nm wavelength where a discontinuous tuning range of 2.7 nm with 3.5 mW output power was observed. However, the tuning range and output power become low due to the low power of LD [14].

Lars Hildebrandt et al have designed a GaN-based laser diode with antireflection coating and operated in littrow configuration [7]. The total tuning range of 4 nm and an optical output power of up to 30 Mw were observed. However, around 10 nm tuning range was observed by using a plane mirror fixed parallel to the tuning of the diffractive grating [15].

ECDLs based on a transmission diffraction grating in Littrow configuration has been developed at 650 nm wavelength of light. A tunable range of 12 nm and a CW output power of more than 20 mW was proposed [15]. Tanaka et al also demonstrated an external cavity laser with a wavelength of 405 nm and output of 80 mW [16]. This power is 2.6 times the power previously observed by Hildebrandt. A high output power of 400 mW in CW operation and spectral width of 0.02 nm was developed by N Ruhnke 2014 [17].

By using diode laser with diffractive mirror in littrow or Littmann configuration, it is not possible to extend the wavelength for a long range. Considering this case, researcher analyzed diode laser with doped fiber for extending the tunable range and increasing output power.

4. Developments in ECDL System with Doped Fiber:

In the telecom windows, Pr3+, Nd3+, and Yd3+ are the most promising options for fiber amplifiers. Various research types have been conducted using this kind of amplifier. Out of all of them, only Pr3+ doped fiber exhibits fluorescence gain across the visible spectrum [18]. For the infrared spectrum, Pr3+ doped fiber was effectively used [18], [19], and [20]. Trivalent Pr3+ is a special kind of optical activator that can produce infrared emission for optical amplification and simultaneous blue, green, and red emissions (19) for laser action or optical imaging. The first thulium-doped glass laser with a 44-mW maximum output power was proposed by Henna et al. From 1780 to 2056 nm, a vast tuning range of 276 nm was covered by the system [21]. Using a Pr3+ doped flurozirconate fiber laser, CW lasing operation was observed later in 1991 in the visible and near-NIR range. At the time, the output power was 100 mW and the tunable range was 60 nm. J. Y. Allain used Pr3+ fluoride fiber to study CW lasing around visible regions concurrently. They saw a green laser with a 15% slope efficiency and a 50-mW output power [5].

Subsequently, in 1995, the tunability within the visible region in Pr3+/Yb3+ doped ZBLAN optical fiber was observed using CW laser [22]. It was possible to generate 300 mW of output power for 760 mW of launch pump power at a pump wavelength of 860 nm. It was 20 mW for the green region at 200 mW launched power and 45 mW for the orange region at 430 mW launched power. In 2003, photoinduced Bragg gratings in germanosilicate fibers and Pr3+/Yb3+ doped fiber was also found to exhibit tunability. For a pump power of 800 mW, an output power of roughly 100 mW was demonstrated [23]. Furthermore, for all visible wavelength bands, Pr3+ doped flurozirconate lasers have been proposed to use GaN blue laser diode as a next-generation pumping source [24], [25], [26], [27].

Using Pr3+ doped fiber, Okamoto et al. demonstrated a tunable GaN laser for wavelengths greater than 300 nm (28). With an output power of 400 mW, a high-power tunable laser based on GaN was demonstrated [17]. Recently, double-clad Pr3+ doped ZBLAN fiber was used to demonstrate ECDL. A 443 nm peak wavelength GaN diode was used to pump the fiber. A unique type of fiber known as double-clad fiber has a single-mode inner core and a multimode inner cladding. Consequently, it is simple to couple additional power into the cladding area, increasing the fluorescent power. It was possible to obtain lasing with an output power of 1.07 W by using this kind of double-clad [29]. The development of a visible tunable laser with double-clad fiber could mark a significant advancement in optical coherence tomography and profilometry systems soon.

5. CONCLUSION

Because real-time measurement is required in industrial and medical systems, ECDL is one of the key technologies in the ongoing development of optical communication and detection systems. Simultaneously, tomography and profilometry systems also need a lot of power and a large tunable range. The most appealing amplified component for covering the visible band region is Pr3+ doped fluoride fiber. Regarding this matter, double-clad Pr3+ doped fiber is already highly favored. In the future, double-clad fiber based on GaN semiconductor laser will allow Ecoverage of all visible bands. Lastly, a visible frequency swept laser with high power and a large tunable range can be developed using a high-speed scanner.

Declaration by Authors

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