Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp63-64

Development of half-cladding semiconductor photonic device structure for surface transmission of light waves

Naokatsu Yamamoto[1], Daisuke Murakami[2], Hiroki Fujioka[2], Kouichi Akahane[1], Tetsuya Kawanishi[1], Hideyuki Sotobayashi[3], and Hiroshi Takai[2]

[1]National Institute of Information and Communications Technology
4-2-1 Nukui-kita, Koganei, Tokyo 184-8795, Japan
E-mail: naokatsu@nict.go.jp
[2]Tokyo Denki University
2-2 Nishiki-cho, Kanda, Tokyo 101-8457, Japan
[3]College of Science and Engineering, Aoyama Gakuin University
5-10-1-L218 Fuchinobe, Sagamihara, Kanagawa 229-8558, Japan

1. Introduction

Semiconductor-based light-emitting devices are critical components that can be used in a range of applications such as optical communication and sensing of bio-environment materials, as well as in displays [1]. Recently, controlling of light wave conditions such as the emitting wavelength, bandwidth, optical-mode, and phase has been studied intensively toward the development of high-efficiency and high-performance light sources [2, 3]. An artificial periodic refractive-index structure like a distributed-feedback (DFB) is considered suitable for controlling light wave properties in the light source [4]. It is also generally known that artificial periodic structures need to exist near the optical-gain region in the light source for achieving efficient control of light wave properties. However, complicated device-process sequences with a high aspect ratio are required for fabricating artificial structures since thick-cladding layers are generally used for effectively confining light waves in the gain-region of photonic devices.

To solve these issues, we have proposed a half-cladding semiconductor photonic device as a novel device structure. In its structure, it is possible for there to be no upper cladding layer for confining the light wave. That is, the light wave can be confined and transmitted near the device surface with the help of two low-refractive-index regions: a lower cladding layer and air. Effective control of the light wave properties can therefore seemingly be achieved without the complicated device-process sequence, since the half-cladding photonic device structure can simply include artificial surface microstructures with a low-aspect-ratio.

More recently, a light emission from the half-cladding semiconductor photonic device was successfully realized under low-current injection at room temperature (RT). In this paper, we report the fabrication sequence and characteristics of the fabricated half-cladding semiconductor laser (HaCL) structures.

2. Fabrication of half-cladding semiconductor laser structure

A III-V compound semiconductor crystal (aluminum gallium arsenide [AlGaAs]) was used for fabricating the light source, bearing a half-cladding photonic device structure as shown in Fig. 1. Triple-stacked multi-quantum wells (MQWs) of InGaAs/GaAs were used as the optical gain medium in the active layer for the Thousand-band (T-band; 1-μm waveband) [1]. A low-refractive-index cladding layer and the adjusting layer were made of $Al_{0.3}Ga_{0.7}As$. It is expected that the optical mode position can be controlled between the device-surface and active layer by controlling the thickness of the adjusting layer. Moreover, a high-refractive-index GaAs core layer was formed atop the device structure.

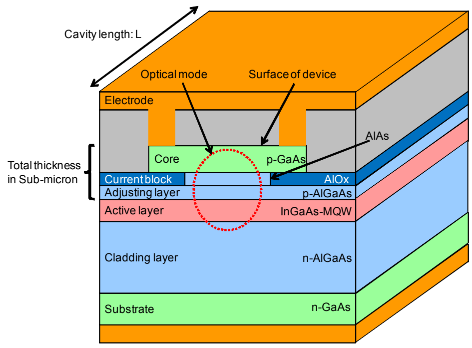

Fig. 1. Schematic cross-sectional image of half-cladding semiconductor laser (HaCL) structure

Details of the fabrication sequences are shown in Figure 2, in which: (a) An AlGaAs/GaAs-based laser crystal for the HaCL was grown on an n-type GaAs (100) wafer by using molecular beam epitaxy (MBE). (b) A ridged waveguide structure was formed by anisotropic chemical wet etching of GaAs on a thin AlAs layer. The thin AlAs layer acts as an etching-stop layer for the chemical wet etching of the GaAs layer. (c) Selective oxidation of the thin AlAs layer was conducted to form a carrier-blocking structure [5]. (d) An SiO_2 passivation layer was deposited onto the device surface by a plasma-enhanced chemical vapor deposition (P-CVD). (e) Etching of the passivation layer was conducted for fabricating an electrical contact region on the GaAs core layer. (f) For constructing ohmic-contacts, metal electrodes were deposited on the top and bottom of the wafer. It is expected that this simple process sequence for fabrication of the HaCL structure can be applied to other material systems such as an InGaAsP/InP for the 1.55-μm

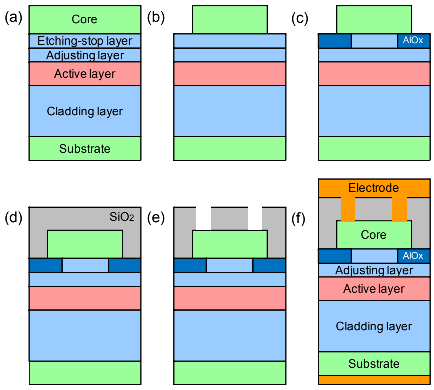

Fig. 2. Process-sequence for fabrication of HaCL structure.

waveband photonic devices, and an AlGaN/GaN for the visible light-emitting devices.

3. Characterization of half-cladding semiconductor photonic device

Figure 3 shows the cross-sectional scanning electron microscopy (SEM) image of the typical fabricated HaCL structure. The dimensions of the fabricated device are as follows; waveguide width: 22 µm; GaAs core layer thickness: 350 nm; adjusting-layer thickness: 300 nm; AlAs thickness: 50 nm; thickness of lower cladding layer (AlGaAs): 1.5 µm; and cavity length L: 2 mm. Thus the total thickness between the device surface and top of the active layer is as low as 700 nm in a sub-micron scale. This thickness is considered to be thinner than that of the convention upper-cladding layer. The cross-sectional SEM image is found to be similar to the schematic image shown in Fig. 1.

A light emission is confirmed as occurring from the HaCL structure under the current injection conditions at RT. Figure 4 shows dependence of emission intensity on the current. The threshold current is found to be as low as I_{th}=110.5 mA. The inset in Figure 4 shows an emission spectrum of the HaCL structure under the current injection. Multiple emission-peaks are found to be wavelength around a 1012.2 nm. This wavelength is considered suitable for ground-state emission from the MQWs in the active layer.

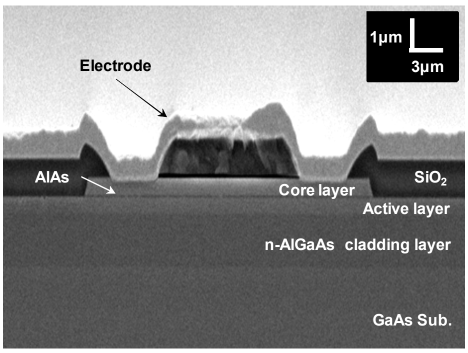

Fig. 3. Typical SEM image of cross-sectional view of a fabricated HaCL structure.

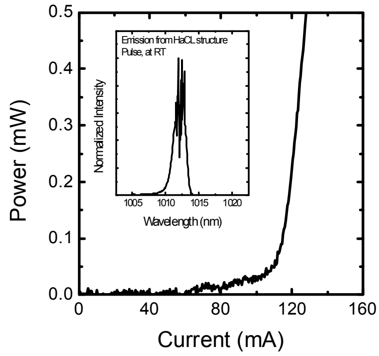

Fig. 4. Dependence of emission power on current of HaCL structure; inset shows emission spectrum from HaCL structure under the current injection.

We also confirmed that a near field pattern (NFP) of the light emission can be observed near the device surface of the fabricated HaCL structure using a microscopic infrared-imager. From these experimental results, therefore, we expected that a laser operation and transmission of the light wave near the device surface could be achieved in a proposed novel half-cladding photonic device structure.

4. Conclusion

A novel half-cladding semiconductor photonic device structure was proposed and fabricated. We successfully demonstrated the light emission of the half-cladding semiconductor light source under current injection at RT. As the half-cladding structure, the total thickness between the device surface and top of the active layer is as low as the sub-micron scale. Therefore, it is expected to extend into control of the light wave properties with artificial surface microstructures that have a low aspect ratio in the fabricated half-cladding semiconductor structure. We believe that the proposed half-cladding semiconductor laser (HaCL) structure will become a breakthrough in useful device structures for optical communications, and sensing.

Acknowledgements

We would like to thank Dr. I. Hosako, Dr. A. Kanno, Dr. I. Watanabe, Dr. Y. Yamashita, and Dr. Y. Matsushima from NICT for their encouragement, and Dr. R. Katouf, Yokohama National University. We would also like to thank the staff of the Photonic Device Laboratory at NICT.

Refferences

[1] N. Yamamoto and H. Sotobayashi: Proc. SPIE **7235** (2009) 72350C.

[2] N. Yamamoto, K. Akahane, T. Kawanishi, R. Katouf, and H. Sotobayashi: Jpn. J. Appl. Phys. **49** (2010) 04DG03.

[3] E. U. Rafailov, M. A. Cataluna, and W. Sibbett: Nat. Photonics **1** (2007) 395.

[4] M. Aoki, H. Sano, M. Suzuki, M. Takahashi, K. Uomi, and A. Takay: Electron. Lett. **27** (1991) 2138.

[5] J. M. Dallesasse, N. Holonyak Jr., A. R. Sugg, T. A. Richard, and N. Elzein: Appl. Phys. Lett. **57** (1990) 2844.