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# Gain-Coupled Distributed-Feedback Effects in GaAs/AlGaAs Quantum-Wire Arrays

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## Abstract

GaAs/AlGaAs quantum-wire (QWR) gain-coupled distributed-feedback (GC-DFB) lasers are fabricated and characterized. Constant metalorganic chemical vapor deposition (MOCVD) growth is used to avoid grating overgrowth during the fabrication of DFB structures. Numerical calculation shows large gain anisotropy by optical feedback along the DFB directions near Bragg wavelength. DFB lasing via QWR active gratings is also experimentally achieved.

**Keywords** : quantum wires, distributed feedback, MOCVD

## 1. Introduction

The one dimensional (1-D) band edge singularity in the distribution of the density of states (DOS), represented by $1/\sqrt{E}$, has stimulated many scientists and engineers to do research on semiconductor quantum wire (QWR) structures and their applications to various devices for the last decade [1-3]. Despite such an effort however most experimental results have lagged behind the expectation due to the gap between the current semiconductor technology and a theory. The V-groove QWR is one of the long-run and representative nanostructures to have two dimensional (2D) bandgap patterning. It has several advantages such as easy fabrication and good controllability of the shape and size compared to the QWR structures fabricated by another means [4]. However, the V-groove QWR has suffered from side-wall quantum wells (QWs) simultaneously grown with QWRs on patterned substrates, deteriorating QWR performance. On top of that, Fabry-Perot type QWR lasers, one of the popular applications of the QWRs, are not very ideal approaches to fully utilize QWR performance due to low optical confinement and light propagation parallel to the wire axis - weak transverse electric (TE) polarization along the emitting direction.

One of the ideas to relieve these problems is to use QWR gain coupled distributed feedback (GC-DFB) structures. This idea, first proposed by Walther, et al. [5], was derived from a perfect periodic-gain structure of the QWR array. By adjusting DFB periodicity to QWR gain, we can use the benefits arising from QWRs and GC-DFB effects. The GC-DFB lasers have higher single-mode yields and immunity to facet reflections [6] as compared to the conventional index-coupled DFB lasers.

Some results on these devices have been reported; however, most of them were achieved at cryogenic temperatures due to interface-related problems occurred during grating overgrowth [7]. In this regard, eliminating the overgrowth step is highly required to reduce the problem and is eventually good for reliable and low-cost manufacturing of DFB lasers. This is particularly

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true for AlGaAs/GaAs GC-DFB lasers because first alloys with high aluminum contents are difficult to overgrowth due to oxide formation, and second more stringent requirements are put to the epitaxy for the GC-DFB lasers.

In order to realize our device concept, we developed constant metalorganic chemical vapor deposition (MOCVD) growth on sub-$\mu$m pitch gratings, by which conservation of the gratings was achieved even after growth of a few $\mu$m-thick AlGaAs cladding layer.

In this paper, GaAs/AlGaAs GC-DFB lasers with a QWR active grating was fabricated by a single MOCVD step. Lasing was achieved at 13mA via GC-DFB using QWR active gratings under room temperature (RT) pulse operation. The threshold gain anisotropy near Bragg wavelength was investigated in both theoretical and experimental aspects to discuss the possibility of achieving GC DFB effects in these devices.

## 2. Experiment

The cross-sectional scanning electron microscopy (SEM) image and a schematic of the QWR GC-DFB laser are shown in Fig. 1. The laser structure was grown by low-pressure MOCVD on V-groove arrays (0.36-$\mu$m pitch and 0.19-$\mu$m depth) of GaAs. The gratings were fabricated by holographic photolithography and chemical wet etching. From the bottom, 0.1 $\mu$m thick $n$-GaAs buffer layer, 1-$\mu$m-thick n-$Al_{0.38}Ga_{0.62}As$ lower cladding layer, 0.12-$\mu$m-thick undoped $Al_{0.2}Ga_{0.8}As$ guiding layer, three 5-nm-thick GaAs QWRs separated by two undoped 10-nm-thick $Al_{0.2}Ga_{0.8}As$ barrier layers, 0.12-$\mu$m-thick undoped $Al_{0.2}Ga_{0.8}As$ guiding layer, 1-$\mu$m-thick $p$-$Al_{0.5}Ga_{0.5}As$ upper cladding layer, and 0.2-$\mu$m-thick GaAs $p^+$ contact layer are grown consecutively. Next, ~5 $\mu$m-wide ridge structures are fabricated in the <011> direction, by selective etching for lateral confinement. The polymide of thickness 100 nm is spin-coated on the samples for current restriction.

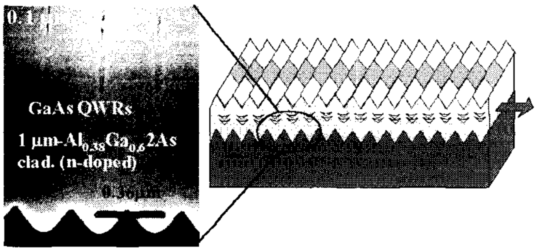

Fig. 1. The cross sectional SEM image (left) and conceptual image (right) of the GaAs/AlGaAs QWR GC-DFB laser

## 3. Results and Discussion

The change of dispersion gain curves near Bragg wavelength with regard to gain constant g was simulated by numerically calculating the complex propagation coefficient $\gamma$ of the present laser in order to confirm the feasibility of the proposed device. In general, a coupled wave analysis has been so far used to determine the $\gamma$ in DFB lasers; however, a specially-designed finite element analysis [7] was used in this calculation due to the complexity of the present DFB lasers. Figure 2 shows a cross-sectional mesh diagram of the QWR GC-DFB laser used in the analysis, where a periodic condition was assumed to the left and right boundaries and a zero-reflection condition was assumed to the upper and lower boundaries.

The normalized modal gain $Im[(\gamma/k_o]$ calculated near Bragg wavelength at $g=2000\ cm^{-1}$ , is also shown

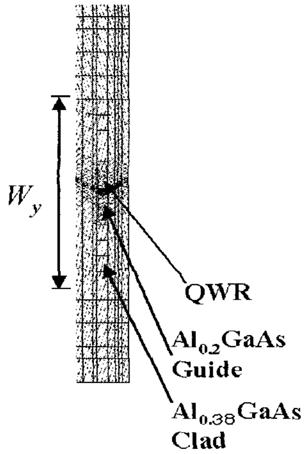

Fig. 2. A DFB structure used for numerical calculation g.

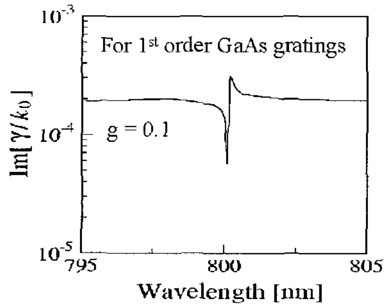

Fig. 3. Dispersion gain curve showing an imaginary part of complex propagation constant.

in Fig. 3. There appear a dip and peak at the imaginary part of the propagation constant. This corresponds to the transition of the mode pattern where the node and anti-node of the propagation modes overlaps into the QWR. There is only one gain peak at the Bragg wavelength. Therefore modal competition in the conventional index guided DFB structure; in other words, two modes at the symmetrical position form the Bragg wavelength were removed. Not shown here, a change in dispersion gain curves from index- to gain-coupling was occurred as increasing the g.

Figures 4(a) and 4(b) show emission spectra taken near threshold for a laser with 550-(m-long cavity at RT and photoluminescence (PL) spectra measured at three different temperatures, respectively. The stimulated emission was observed at 13mA near QWR gain (~ 810 nm) with some trace of the stopband (< 4nm) having a large threshold gain difference. The temperature dependent PL measurement was also carried out with the same, corresponding QWR laser to identify the origin of lasing. Two dominant peaks were observed all the time (15 - 298 K), where the shorter wavelength was assumed to be QWs and the longer one to be QWRs, based on the temperature- and polarization-dependent PL; they were located at 796 nm for QW (FWHM-14.3 meV at 113 K) and at 810 nm for QWR (FWHM-19.1 meV at 113 K) at RT.

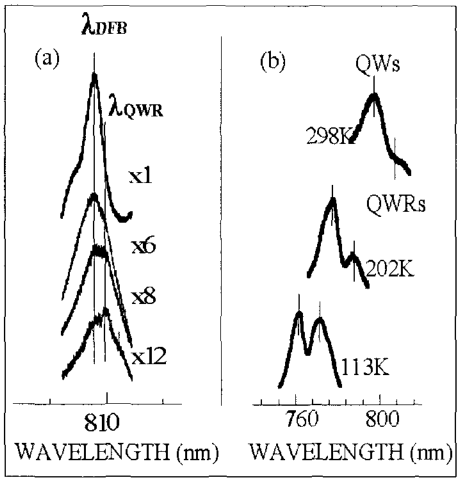

Fig. 4. Evolution of lasing spectra near Bragg wavelength (a) and temperature dependent PL spectra of the GaAs/AlGaAs QWR GC-DFB lasers.

Because of gain asymmetry, it seems to be easy to have lasing from QWs rather than QWRs, especially at elevated temperature. Nevertheless, the fact that lasing has occurred from near-QWRs should be interpreted by the DFB (filtering) effect using a QWR active grating. Reduced threshold current compared with the conventional DFB lasers, can also be attributed to the benefits from the use of QWRs. The strong stimulated emission spectra have not been achieved with the present lasers; however, the consistency in emission wavelength between the PL and lasing spectra as well as the large threshold gain difference near the stopband indicates that current lasing was achieved via GC-DFB using QWR active gratings. Further investigation is required to gain more precise information on these devices.

## 4. Conclusions

The GaAs/AlGaAs QWR GC-DFB laser was successfully fabricated by a single MOCVD growth step on 0.36-$\mu$m pitch gratings of GaAs. The feasibility of the proposed structures was confirmed by numerical calculation on a DFB waveguide mode analysis. The consistency of the photon energies of the lasing and PL peaks from the QWRs was given as evidence for lasing via GC-DFB effects in these devices along with a large threshold gain difference near the Bragg wavelength.

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