Dual-wavelength operation of GaSb-based diode lasers with asymmetric coupled quantum wells

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Abstract: The DBR diode lasers with asymmetric tunnel coupled quantum wells having built-in resonant second order nonlinearity were designed and fabricated. The devices can generate comparable power in two bands near 2 um separated by ~13 meV as required for intracavity difference frequency generation.

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The dual-wavelength operation of semiconductor lasers is required for various applications including extra- or intra-cavity difference frequency generation (IC-DFG). The quantum cascade lasers (QCLs) with built-in resonant second order nonlinearity that operate simultaneously at two mid-infrared wavelengths selected by distributed feedback and/or external cavity gratings can generate THz radiation [1]. The THz emitters based on IC-DFG in two-wavelength QCLs require highly sophisticated fabrication methods to deal with the fundamentally high values of the threshold electrical power in QCLs.

The interband lasers with built-in resonant second order nonlinearity that require orders of magnitude lower threshold electrical power inputs can be realized within antimonide material system [2]. The asymmetric tunnel coupled quantum wells (QWs) can generate optical gain for TE polarization utilizing transitions between two electron subbands and one hole subband, i.e. e1-hh1 and e2-hh1 (Figure 1a). The energy separation between electron subbands can correspond to the THz region and be controlled by thickness of the tunnel coupling barrier. The IC-DFG of the TM polarized photons can be realized in the devices utilizing such an active region provided the corresponding lasers are set to operate at two wavelength matching the e1-hh1 and e2-hh1 transitions. One possible approach can be based on Y-branch laser design with two branches having high order distributed Bragg reflectors (DBR) of different periods, see, for instance, [3] where laser operation at two wavelength separated by ~10 cm^{-1} (~1 meV) was demonstrated.

In this work we explore the possibility to stabilize the wavelength of the GaSb-based diode lasers with asymmetric tunnel-coupled active region using high order DBR mirrors. We designed and fabricated narrow ridge lasers having 6^{th} order DBR reflectors of two different periods (1723 and 1765 nm). The DBR period difference corresponded to about 13 meV difference in the corresponding laser mid-infrared photon energies. The laser heterostructures were grown by solid source molecular beam epitaxy and contained two asymmetric tunnel coupled QWs in its active region (Figure 1a). The 5-to-6-µm-wide narrow ridge waveguide lasers were defined by chlorine-based inductively coupled plasma reactive ion etching. The ridges were etched through top p-cladding and active region and into the bottom n-cladding. The 6^{th} order DBR reflectors were etched prior to the ridge formation using mask defined by e-beam lithography. The etching in DBR section was stopped near the interface between p-cladding and waveguide core layer (insert to Figure 1b). We tested uncoated 1-mm-long Fabry-Perot (FP) and 1-mm-long DBR lasers having ~300-µm-long Bragg reflectors. The devices were either the individual ridges or the twin-ridges separated by ~30-µm and connected in parallel. Figure 1b plots the corresponding light-current characteristics of the single FP and DBR devices with grating period of 1765 nm as well as that of twin-ridge DBR device with 1723 and 1765 nm grating periods. The FP lasers generate multimode output spectra correlated with the gain peak (Figure 2a) at 20, 40 and 60 ^{0}C. The gain peak corresponds to the peak in amplified spontaneous emission spectra (ASE) (not shown) and matches the e1-hh1 transition energy as seen in photoluminescence spectra of the laser wafer (Figure 2a). The emission spectrum of the DBR laser with grating period of

1765 nm is narrow and detuned from the gain peak (by up to 25 meV at 60 ^{0}C). The ASE spectra of the DBR device are broadened covering the range from the gain peak to the DBR feedback peak (Figure 2a). The DBR lasers with grating period of 1723 nm generate photons with energy ~13 meV larger at 15 ^{0}C despite more than 25 meV detuning from the gain peak (Figure 2b plots spectra of the twin-ridge device). When lasers are cooled to about 230 K the DBR1765 feedback aligns with e1-hh1 transition while DBR1723 feedback aligns with e2-hh1 one. At this temperature the twin-ridge device generates roughly the same power at both wavelengths in the wide current range (Figure 2b), which is optimal for IC-DFG.

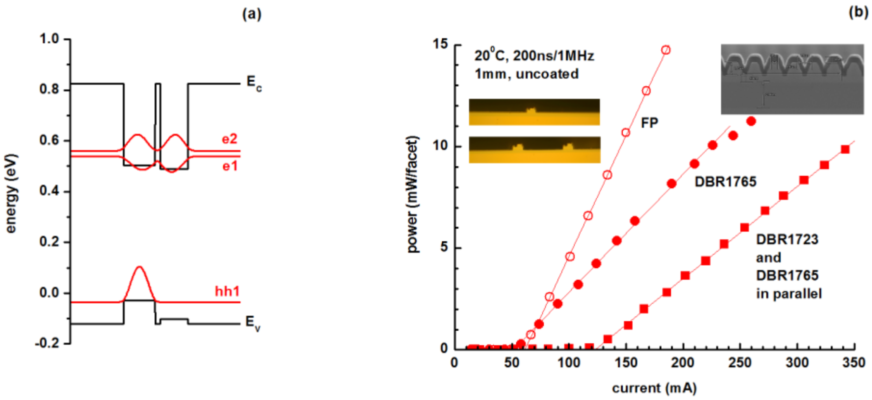

Figure 1. (a) Calculated band diagram and envelope wavefunctions of the asymmetric tunnel coupled QWs used in laser active region; (b) Light-current characteristic of 1-mm-long uncoated Fabry-Perot (FP) and DBR devices with 300-µm-long Bragg reflector section. Insets show the SEM image of the cross-section of the etched grating and optical images of the individual narrow ridge and double-ridge devices (separation is 30 µm).

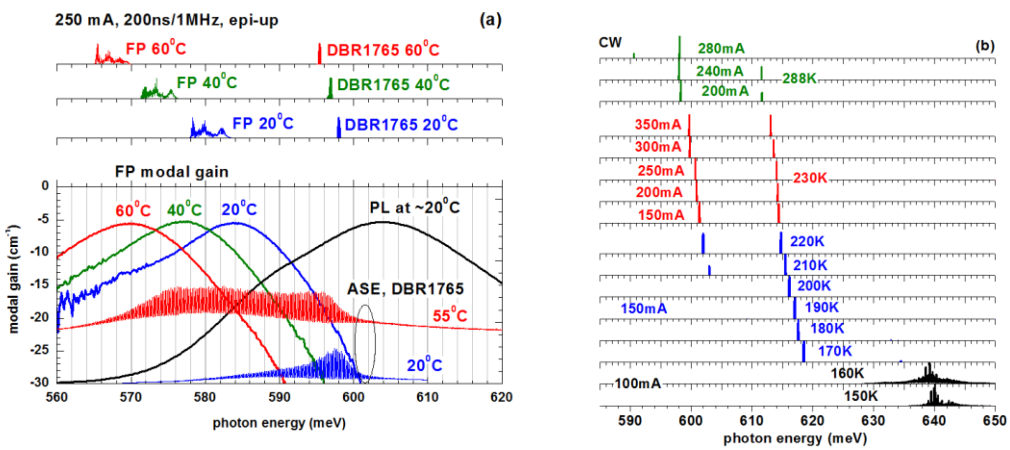

Figure 2. (a) Top - Emission spectra of the FP and DBR devices with period 1765 nm measured at 250 mA at 20, 40 and 60 ^{0}C. Bottom – optical gain spectra measured for FP lasers, ASE emission spectra of the DBR laser and wafer photoluminescence spectrum; (b) Emission spectra of the twin-ridge DBR laser measured in wide temperature range.

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