Dual-wavelength Bragg reflectors using GaAs/AlAs multilayers

C.P. Lee, C.M. Tsai and J.S. Tsang

Indexing terms: Grating filters, Optoelectronics

Dual-wavelength Bragg reflectors have been demonstrated using GaAs/AlAs multilayer heterostructures. Desired reflection bands can be obtained by adding proper phase shifters in a GaAs/AlAs periodic multilayer structure. The structure is based on the digital representation of the addition of two periodic functions.

Bragg reflectors fabricated using multistacks of semiconductor heterostructures have found wide use in optoelectronic devices recently. With advances in epitaxial growth technology, it is now possible to tailor high quality multilayer Bragg reflectors for many different applications. Vertical-cavity surface emitting lasers [1], resonant cavity detectors [2] and phototransistors [3], and reflection modulators [4,5], etc. have all been built with the concept of built-in Bragg reflections in their device structures. Because semiconductor multilayer Bragg reflectors consist of periodic heterostructures, which are easily controlled by epilayer growth techniques, it is possible to build reflectors with designed reflectivity spectra. In this Letter we report the design and fabrication of dual-wavelength Bragg reflectors using GaAs/AlAs multilayers. Proper phase change and/or delay are used in the structures for the desired reflectivity spectra.

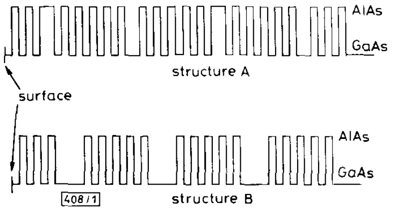

Fig. 1 *Two layer structures of dual-wavelength reflectors used in study*

Two structures were used to build the dual-wavelength reflectors. They consist of alternating GaAs/AlAs quarter-wavelength stacks grown by molecular beam epitaxy (MBE). The layer structures are shown in Fig. 1. The wavelength used for the design was 1.05μm, so the quarter-wavelength thicknesses for each GaAs layer and AlAs layer was 750 and 890Å.

The idea behind the dual wavelength reflector structures shown in Fig. 1 is based on the addition of two periodic functions. We have used a similar idea to fabricate surface gratings to broaden the absorption spectrum of quantum well infra-red detectors [6]. Let the combined function be

$$\sin\left(\frac{2\pi}{d_1}x\right) + \sin\left(\frac{2\pi}{d_2}x\right)$$

where d_1 and d_2 equal halves of the wavelengths for the desired reflection peaks divided by the material refractive index. The above expression is the same as

$$2\sin\left(\frac{2\pi}{d}x\right)\cos\left(\frac{2\pi}{D}x\right)$$

where

$$\frac{1}{d} = \frac{1}{2}\left(\frac{1}{d_1} + \frac{1}{d_2}\right) \quad \text{and} \quad \frac{1}{D} = \frac{1}{2}\left(\frac{1}{d_1} - \frac{1}{d_2}\right)$$

Therefore the original bi-periodic function becomes a sinusoidal function with a period d modulated by a cosine function with a much longer period, D. If we take the sine and the cosine functions as square waves, the digital representations become similar to those shown in Fig. 1. These structures can be easily realised by multilayer heterostructures. The period d of the new structure is half the centre wavelength λ_0 which is between the two reflection peaks. Therefore each period d consists of a GaAs/AlAs pair with each layer equal to a quarter of the centre wavelength. If $D = C \times d$, the two Bragg reflection peak wavelengths can be expressed in terms of the centre wavelength:

$$\lambda_1 = \frac{C}{C+1}\lambda_0 \quad \text{and} \quad \lambda_2 = \frac{C}{C-1}\lambda_0$$

Structure A in Fig. 1 was designed with $D = 12d$. Therefore, with a centre wavelength of 1.05μm, the two reflection peaks occur at 0.97 and 1.14μm. The calculated reflection spectrum is shown in Fig. 2*a*. The assumed reflactive indices for GaAs and AlAs are 3.5 and 2.95, respectively. The measured spectrum is shown in Fig. 2*b*. The measurement was normalised against the reflection spectrum of an Al coated GaAs. Reflectivity greater than 1 is probably due to imperfections in the Al coating. Reasonable agreement is obtained between the measured and the calculated results.

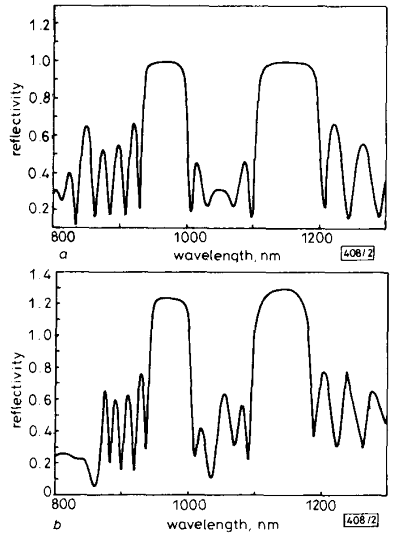

Fig. 2 *Calculated and measured reflection spectra of structure A shown in Fig. 1*
a Calculated
b Measured

Structure B in Fig. 1 has a different design. In this case $D = 13d$, which corresponds to reflection peaks at 0.928 and 1.083μm. At the places where the phase change occurs (where the cosine changes sign), a pair of GaAs/AlAs is replaced by a λ/2 GaAs layer. This is why an extended region of GaAs exists for every five pairs of GaAs/AlAs. The replacement of the GaAs/AlAs pair by the λ/2 GaAs layer does not cause any fundamental change in the

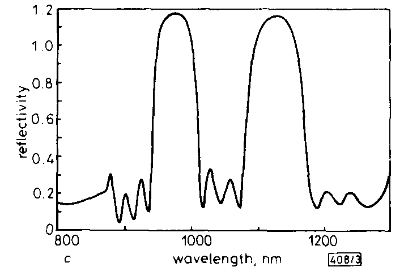

Fig. 3 *Calculated and measured reflection spectra of structure B shown in Fig. 1 and measured reflection spectrum of structure B but with a quarter-wavelength SiO$_2$ antireflection coating*

a Calculated reflection spectrum of structure B

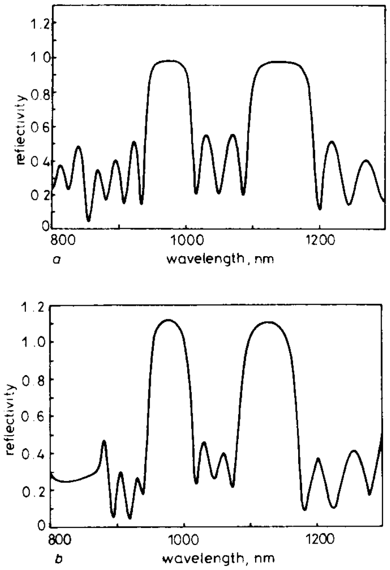

Fig. 3 *Calculated and measured reflection spectra of structure B shown in Fig. 1 and measured reflection spectrum of structure B but with a quarter-wavelength SiO_2 antireflection coating*

b Measured reflection spectrum of structure B
c Measured reflection spectrum of structure B with antireflection coating

reflection spectrum; it merely demonstrates the flexibility of the design. Fig. 3*a* and *b* show the calculated spectrum and the measured spectrum. Again reasonable agreement is obtained. It should be pointed out that at short wavelengths (below 0.9μm), the material dispersion and the absorption of GaAs were not included in the calculation, which results in some discrepancy between the measured and the calculated result. The reflection spectrum can be further improved by adding a quarter-wavelength SiO_2 antireflection coating on the surface to suppress the reflection of light with wavelengths other than the desired peaks. Fig. 3*c* is the measured spectrum. The peak to valley reflection ratio is clearly improved.

In conclusion, we have demonstrated dual-wavelength Bragg reflectors using multilayer GaAs/AlAs heterostructures. The structures incorporate the correct phase changes to cause two-band reflection. The reflectors can be easily fabricated using modern epitaxial techniques and should find applications in various optoelectronic devices.

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High-power high-gain monolithically integrated preamplifier/power amplifier

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Indexing terms: Integrated optoelectronics, Semiconductor lasers, Optical amplifiers

The monolithic integration of an index-guided single lateral mode optical preamplifier with a power tapered semiconductor laser amplifier is reported. With a coupled input power of only 6 mW, 4.5W of output power is obtained at 810nm. The far-field pattern is dominated by a diffraction-limited single lobe. An internal small signal gain of 35dB is demonstrated.

Obtaining a high-power diffraction-limited optical output from a semiconductor laser diode has been an important goal that has been pursued for several years. For instance, many applications require a high-power optical source. They include nonlinear frequency conversion, free-space optical communication and efficient pumping of solid-state lasers. The most successful approach towards this goal has been the master oscillator power amplifier (MOPA) approach. For discrete MOPAs, broad-area amplifiers have demonstrated up to 21W pulsed [1] and 3.3W CW [2] output power when injected with incident powers of 500 and 400mW, respectively. Tapered amplifiers have demonstrated up to 3.5W CW [3], 4.5W CW [4] and 2W CW [5] output power when injected with incident powers of 90, 150 and 25mW, respectively. For monolithically integrated MOPAs, up to 3W CW output power has been demonstrated [6]. Because diode-to-diode amplification is compact, efficient and cost effective, high-gain amplifiers with low input power are desirable. In this Letter, we describe the monolithic integration of an index-guided single lateral mode optical preamplifier with a power tapered semiconductor laser amplifier. We have obtained as much as 35dB internal small signal gain and more than 4.5W pulsed output power was produced with only 6 mW of coupled input power.

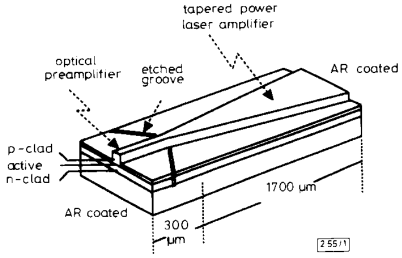

Fig. 1 *Schematic structure of tapered amplifier*

Ridge width is 2.5μm, and tapered angle is 11.7°

The devices were fabricated from single-quantum-well GaAs/AlGaAs GRINSCH material with a lasing wavelength of 810nm. The schematic structure is shown in Fig. 1. The optical preamplifier consists of a 2.5μm wide ridge 300μm in length, which is much longer than the Rayleigh length associated with the input signal. It produces a well behaved narrow single-lateral-mode optical beam before it is injected into the tapered power amplifier. A relatively