the visible laser is 500 × 200 × 1 μm. The multi-stripe infrared laser chip consists of five stripes located at a distance of 500 μm from each other. Each stripe has p-n junction of 2000 × 100 × 1 μm. Rear facets of both chips are HR coated (5% and 95% for visible and infrared lasers respectively), output facets are AR coated (0.1% and 4% for visible and infrared lasers respectively). The complete experimental setup is described in details in.[2]

Multiwavelength regime of operation is depicted in Fig. 1. Fig. 1a demonstrates the multi-wavelength output spectrum of the visible laser. Five-wavelengths oscillation with a spectral separation between lines of 1300 GHz was achieved with a single diode chip. The overall width of the oscillation spectrum is about 5400 GHz, which constitutes ~80% of the FWHM of the luminescence bandwidth. The total output power of the laser was about 50 mW. Fig. 1b demonstrates the output spectrum of the infrared multiline diode laser.

The design of the laser cavity allows realization of multiwavelength regime of oscillation with any pre-assigned spectral compositions as well as changing of the spectral distance between oscillation lines. Theoretical analysis of the cavity shows that simultaneous operation of 20 independent single mode channels with a spectral separation of 25 GHz and spectral linewidth of 200 kHz is possible. The minimum spectral separation between lines achieved in our experiments, measured with a Fabry-Perot etalon, was 6.2 GHz. The oscillation linewidths of each line were less than 2.1 GHz. The results of this measurements are shown in Fig. 2.

In conclusion, we have demonstrated an external cavity multi-wavelength diode laser based on a novel spatially dispersive resonator scheme. Multi-wavelength oscillation has been achieved with a single broad-stripe diode laser operating at 660 nm and with a 1560 nm multi-stripe diode laser. One of the major advantages of our laser scheme is that it can be build on the basis of a single diode chip as well as a diode array or a multi-striped diode. Excellent reliability of the ML laser, high flexibility in wavelength tuning, its ability to generate virtually any output spectrum structure, high wavelength stability controlled by the external cavity, make it an excellent candidate for telecom applications.

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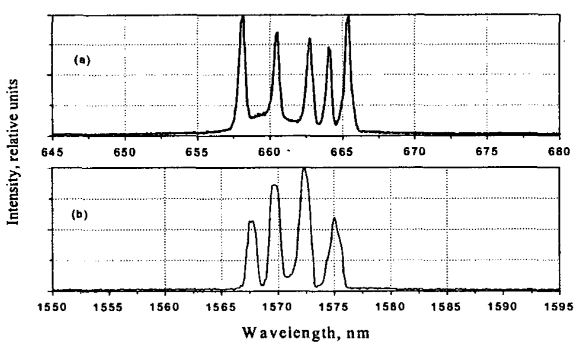
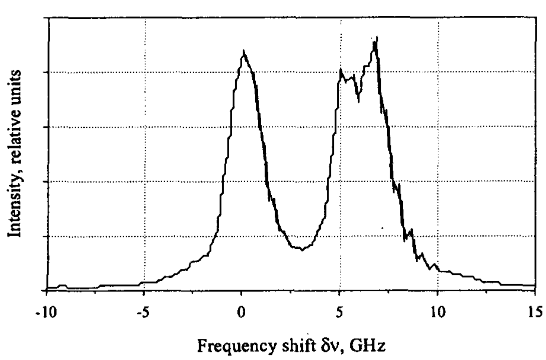



**CWK1 Fig. 1.** Multiline operation of (a)-visible single-chip multiline diode laser, (b)-infrared multistripe diode laser.




**CWK1 Fig. 2.** High resolution measurement of linewidth of each channel in two-wavelength operation with a Fabry-Perot interferometer. This result demonstrates a single longitudinal mode operation.

**CWK2** **5:00 pm**

## Broadly Tunable Dual-wavelength Semiconductor Laser in Optical-communication Band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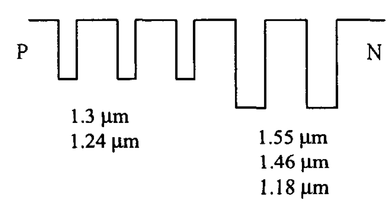
### 1. Introduction

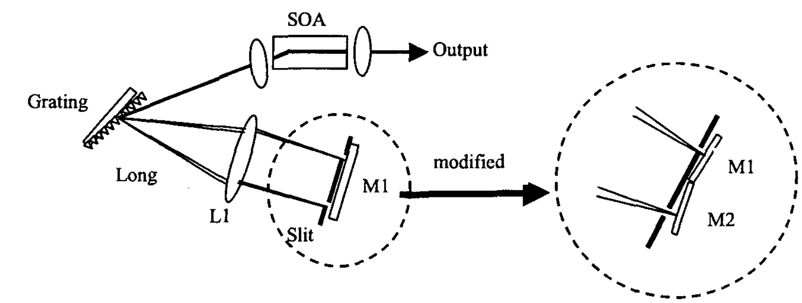
The coming of the information age dramatically increases the requirement on data transferring, so broadband property is highly desired, leading to the development of WDM communication system using optical fibers. Nowadays, the mainly used bands in fibers are near 1.55 μm and 1.3 μm, which has the lowest loss and the minimum dispersion, respectively. Recent research had further reduced the hydroxyl absorption near 1.4 μm in optical fibers. Hence a very broad bandwidth of 300 nm can be utilized for communication in the future. At the present time, the wide Er-doped fiber amplifier can amplify both the C-band (1530 nm ~ 1565 nm) and L-band (1565 nm ~ 1610 nm), but it cannot amplify the band near 1.3 μm.[1] To fully exploit the abundant bandwidth of optical fibers for future WDM system, other techniques are required. Semiconductor lasers/amplifiers using multiple-quantum-well (MQW) engineering[2–4] thus provide alternatives for the broadband purpose. This work reports the successful use of nonidentical MQWs to achieve simultaneously lasing at two wavelengths. The two wavelengths are between 1344 nm to 1514 nm, with the spectral separation tunable from a few nanometers to 170 nm.

### 2. Experiment

To achieve the broadband operation at two wavelengths, both the gain medium and the cavity configuration need to be engineered. For gain medium, we use nonidentical MQW structure for the broadband purpose. There are two $In_{0.53}Ga_{0.47}As$ QWs near the n-cladding layer and three $In_{0.67}Ga_{0.33}As_{0.72}P_{0.28}$ QWs near the p-cladding layer. The QWs are separated by wide $In_{0.86}Ga_{0.14}As_{0.3}P_{0.7}$ barriers. The QW structure is shown in Fig. 1. Due to the nonuniform carrier distribution, the sequential layout of the QWs[4] and other parameters, e.g., barrier width and height as well as the width of separate-confinement heterostructure, are also important for broadband purposes.




**CWK2 Fig. 1.** Nonidentical MQW structures for broadband purpose.



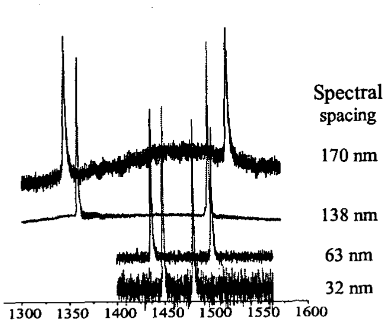

CWK2 **Fig. 2.** External-cavity configuration and modified setup for widely-separated dual-wavelength operation.

Bent-stripe ridge-waveguide semiconductor optical amplifiers (SOAs) were fabricated on those substrates and were used in the cavity for dual-wavelength generation. To simultaneously generate multiple wavelengths in semiconductor lasers, reflected-type grating telescope configuration is widely used, as shown in Fig. 2.[5] However, the exact alignment of the lens (L1) position between the grating and the mirror M1 is difficult, leading to the light beams of different wavelengths between lens L1 and mirror M1 usually nonparallel. The deviation from the parallel direction is particularly severe when the two wavelengths are widely separated. Thus it is impossible to use a single mirror M1 for the simultaneous reflection of both light beams. To overcome the alignment difficulty, we used two mirrors for the long and short wavelengths, respectively, as shown in the modified insert of Fig. 2.

### 3. Results and discussions

By changing the position of the double-slit and the spacing between the two slits, we obtained a series of dual-wavelength spectra. Fig. 3 shows the measured spectra with different separations. Because the gain spectrum of the SOA depends on the injection-current level,[4] simultaneous generation of dual wavelengths also depends on the injection current level. For spectral spacing up to 170 nm, the injection current has to be large. The reason is because the carriers in the $In_{0.67}Ga_{0.33}As_{0.72}P_{0.28}$ QWs are only significant when the injection current is large. The physics behind this phenomenon will be discussed. With better design of MQW structures to improve the uniformity of carrier distribution among the QWs, operation current can be reduced.

The experiment also shows that the amplified spontaneous noise (ASE) is not significant for most of the tuning ranges. The reasons will be discussed.




CWK2 **Fig. 3.** The measured spectra of dual wavelengths.

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**CWK3** Invited **5:15 pm**

## 100 mW External Cavity Laser with a 1405–1575 nm Tuning Range

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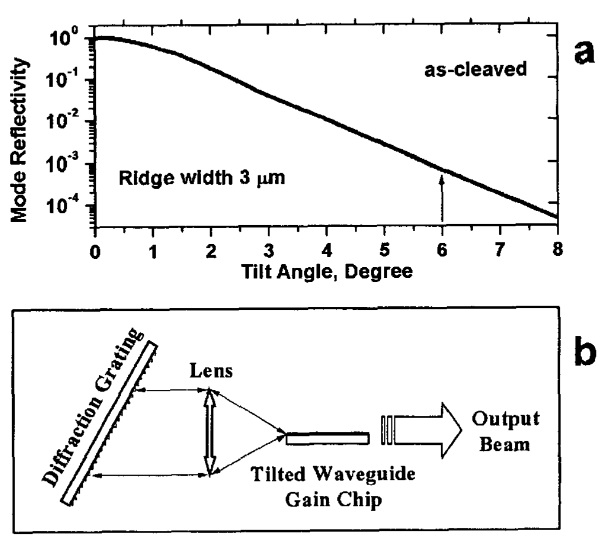
Tunable diode lasers utilizing an external cavity laser (ECL) design can provide many attractive features needed for WDM application such as a very narrow linewidth, wide continuous tuning range, high output power and considerable inventory reduction.[1] The use of tilted or angle waveguide gain chips[2–4] for ECL fabrication eliminates the need for very accurate thickness and refractive index material deposition on one or more of the emitting facets. The elimination of this very low-reflective coating ($R < 10^{-4}$) deposition procedure makes possible mass production of low-cost gain chips. Our modeling shows that tilted waveguide chips even with an as-cleaved facet can have effective reflective coefficient as low as $6 \times 10^{-4}$ if waveguide axis is tilted only by 6° relative to chip facet (Fig. 1(a)). Effective reflective coefficient in Fig. 1(a) was estimated as an overlap of the ridge waveguide mode with the mode reflected from the tilted chip facet. The ridge mode near-field used for this calculation was derived in Gauss approximation from experimental data on the chip far field.

In this paper InGaAsP/InP strained multi-quantum well structures similar to those described in[5] were used for tilted ridge waveguide (TRWG) gain chip fabrication. Lateral mode confinement is provided by a dual-channel ridge waveguide structure prepared by conventional photolithography in conjunction with chemical etching.[5]

The rear and front facets of TRWG chips have conventional anti-reflective coating ($R \leq 2\%$) and reflective coatings, respectively. For our ECL ex-




CWK3 **Fig. 1.** The portion of the ridge waveguide mode reflected back from the as-cleaved facet into waveguide as a function of the incident angle (a), and schematic of the external cavity laser setup (b).