heterostructure indicates that the turn-on delay time can be reduced to about 100 ps at 85°C. Consequently, an *n*-type MD-MQW laser at an optimised donor concentration level is suitable for use as a light source for high-density parallel optical interconnections.

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Integrated external cavity laser composed of spot-size converted LD and UV written grating in silica waveguide on Si

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Indexing terms: Semiconductor junction lasers, Gratings in fibres

The authors report for the first time an external cavity laser composed of a spot-size converted LD and a UV written waveguide grating, both integrated on Si. The laser operates in a singlemode with a side-mode suppression of 37dB. The threshold current is 12mA and the average thermal coefficient is as low as −1.7GHz/°.

Introduction: The singlemode, wavelength stabilised light source is a key device for a wavelength division multiplexing (WDM) optical transmission system. External cavity lasers with a UV written grating in silica fibre [1], or in a silica waveguide [2], are attractive candidates for this light source because their oscillation wavelengths are determined by their Bragg wavelengths, whose thermal coefficients are only one eighth that of a semiconductor LD. In addition, in terms of fabrication, it is possible to obtain a prescribed oscillation wavelength more easily than with a DFB LD since the refractive index of silica glass is stable and reproducible. The introduction of such lasers into practical systems requires the integration of the LD and the grating to ensure stable coupling and mass producibility.

In this Letter we report an integrated external cavity laser for the first time, and demonstrate its feasibility for practical applications. The laser exhibits singlemode, wavelength stable oscillation, which was achieved by using a hybrid integration technique with a silica waveguide [3] and a spot-size converted LD with a tapered semiconductor waveguide (SSC-LD) to provide high efficiency coupling [4].

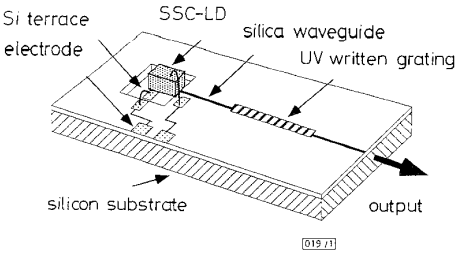

Fig. 1 *Configuration of integrated UV written grating external cavity laser*

Fabrication: Fig. 1 shows the configuration of the proposed external cavity laser. The fabrication process was as follows: a silica waveguide was fabricated on Si and the silica layer was partly etched in order to fabricate a silicon terrace as an LD mounting platform [3]. Then electrode and solder patterns were formed. The 4mm long grating was written by 193nm ArF excimer laser irradiation through a phase mask without hydrogen loading [5]. Finally an SSC-LD was passively aligned with the silica waveguide end and soldered to the silicon terrace. The active region and the spot-size converting tapered waveguide in the SSC-LD were both 300μm long. The output endface of the LD was coated with an anti-reflection film, and the rear facet was high-reflection coated (R-96%). To achieve a singlemode oscillation, the number of longitudinal modes in the cavity within the grating reflection band should be as small as possible. We designed the laser cavity length to be 12mm, which corresponds to a longitudinal mode spacing of 8GHz. The completed laser was 5 mm × 20mm.

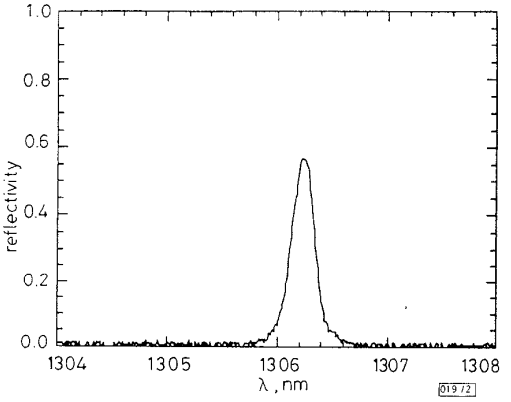

Fig. 2 *Reflection spectrum of UV written grating*

Results and discussion: Fig. 2 shows the reflection spectrum of the grating. The reflectivity at the Bragg wavelength was 57% and the FWHM was 0.22nm (39GHz). There were about five cavity modes within the FWHM. Fig. 3 shows the light-current characteristic of the fabricated laser when its temperature was controlled

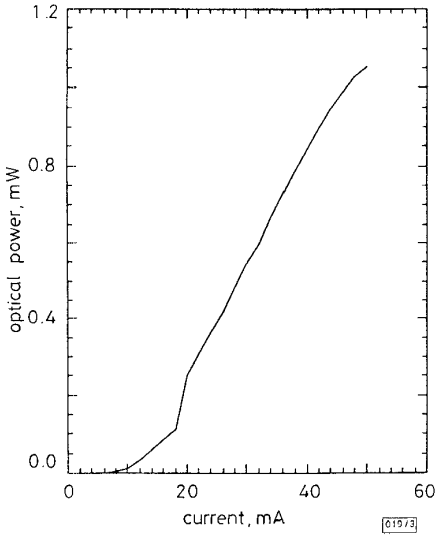

Fig. 3 *Light-current characteristic of integrated laser*
CW, 20°C

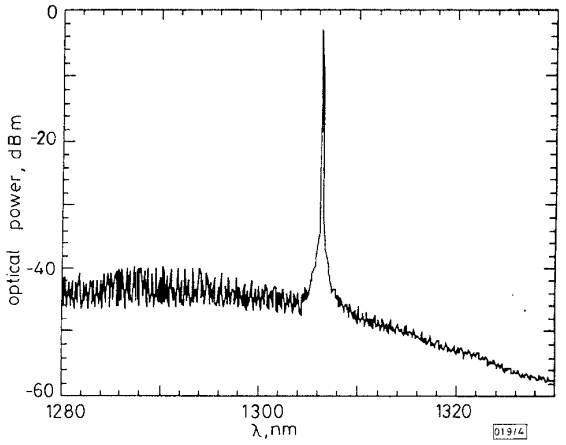

Fig. 4 *Output spectrum of integrated laser*
CW, 35mA, 25°C

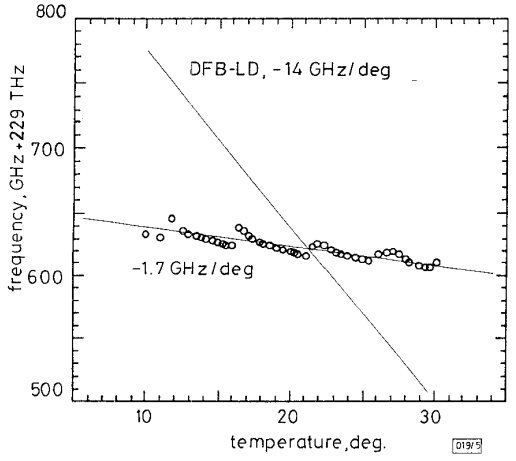

Fig. 5 *Temperature dependence of oscillation frequency*

at 20°C by a thermo-electric cooler. A low threshold of 12mA and a high slope efficiency of 0.030W/A were obtained, resulting from the high coupling efficiency of 4 dB between the SSC-LD and the waveguide [3]. Fig. 4 shows the output spectrum of the laser. We obtained a singlemode oscillation with a side-mode suppression of 37dB. We also measured the spectrum using a Fabry-Perot interferometer with 100MHz resolution and confirmed that there were no side-modes.

The oscillation frequency was measured with a Michelson interferometer frequency counter with <1GHz error, and found to be very stable. This stable oscillation was achieved as a result of the mechanical and thermal stability provided by the LD/waveguide integration. The Si substrate acted as a heat sink. Fig. 5 is the frequency-temperature characteristic of the laser, which shows only slight temperature dependence. The average frequency change of –1.7GHz/° is due to the temperature dependence of the Bragg wavelength of the grating, which corresponds to the sum of the refractive index change of the waveguide glass and the thermal expansion coefficient of the Si substrate. This is one eighth the thermal coefficient of –14GHz/° in conventional DFB lasers. A small mode jump was observed every 5°. This period will be lengthened by optimising the cavity length and bandwidth of the grating.

In addition to stable oscillation, the proposed laser has other advantages resulting from the hybrid integration. It has a simple structure, i.e. no coupling lens and the direct LD mounting technique requires only the LD and waveguide chips. These advantages make the proposed laser a promising candidate for use as a multiwavelength light source in WDM systems.

Conclusion: We have demonstrated a hybrid integrated external cavity laser using an SSC-LD and a UV written grating in a silica waveguide on Si. This laser showed stable singlemode oscillation and only slight temperature dependence, which confirm its feasibility for practical use.

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