Wavelength-selectable laser emission from a multistripe array grating integrated cavity laser

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We report laser operation of a multistripe array grating integrated cavity (MAGIC) laser in which the wavelength of the emission from a single output stripe is chosen by selectively injection pumping a second stripe. We demonstrate a device that lases in the 1.5 μm fiber band at 15 wavelengths, evenly spaced by ~2 nm. The single-output/wavelength-selectable operation, together with the accurate predefinition of the lasing wavelengths, makes the MAGIC laser a very attractive candidate for use in multiwavelength networks.

Wavelength-division multiplexed (WDM) networks employing direct detection techniques are currently attracting a great deal of attention for use in future telecommunication and computer networks.[1–3] Systems using tunable-wavelength transmitters have been investigated and offer considerable promise.[1–3] The source in a tunable-wavelength transmitter may be either a single wavelength-tunable laser or else an array of electrically switched single-wavelength lasers. The outputs from the lasers in the array must, of course, be combined and in order to minimize losses a wavelength specific coupler such as a diffraction grating is preferable.[4] Whatever scheme is employed, the WDM transmitters must operate at and maintain the assigned network wavelengths to a high degree of accuracy. Achieving this at low cost is one of the greatest challenges facing the widespread implementation of WDM systems.

In this letter we report the use of a multistripe array grating integrated cavity (MAGIC) laser[5,6] to provide wavelength-selectable laser emission from a single output port at accurately predetermined wavelengths. A schematic diagram of the MAGIC laser is given in Fig. 1. Identical lasers may be used throughout a WDM network to provide the required network wavelength(s) at each source location. Fabrication of the MAGIC laser entails only standard photolithography, dry and wet-chemical etching techniques, and the lasing wavelengths are accurately determined by the mask geometry and the as-grown laser layer structure. The MAGIC laser is thus readily amenable to large-scale manufacture with tight wavelength tolerances.

The MAGIC laser is essentially a two-dimensional implementation of the external grating cavity laser in which an array of active elements and a fixed, etched-in, diffraction grating replace the single active stripe and movable external diffraction grating of the conventional bulk device. Now, instead of rotating the grating to obtain lasing from the single active element at different wavelengths, the different stripes when separately pumped lase at different wavelengths determined by their position relative to the etched-in grating. We have recently reported the realization of an InP-based MAGIC laser operating over 35 nm in the 1.5 μm low loss fiber band.[5,6] In accord with expectation, the different stripes in the array lased at different, accurately defined, wavelengths.

We report here a different kind of operation of the MAGIC laser—that of a single output/wavelength-selectable laser source. This is achieved by injection pumping a single "output" stripe and simultaneously pumping another, "second," stripe. The two stripes together form a resonant cavity, via the diffraction grating; reflections at the cleaved end facet of each stripe provide optical feedback and cause lasing to occur at the wavelength for which the grating "connects" the two stripes. All that is required is that there be less (or no) gain at the retroreflecting wavelength for each individual stripe. This is automatically achieved if the two-stripe emission wavelength occurs over the spectral region of peak gain of the active material. We have successfully fabricated such a device and report, in this letter, wavelength-selective lasing at linearly spaced wavelengths over a ~27 nm spectral range in the 1.5 μm fiber band.

A bulk-optic laser operating on similar principles, employing a laser stripe array and an external diffraction grating, has recently been reported.[7] An integrated form has also been suggested.[8]

The structure of the MAGIC laser is similar to that of our previously reported InP-based wavelength

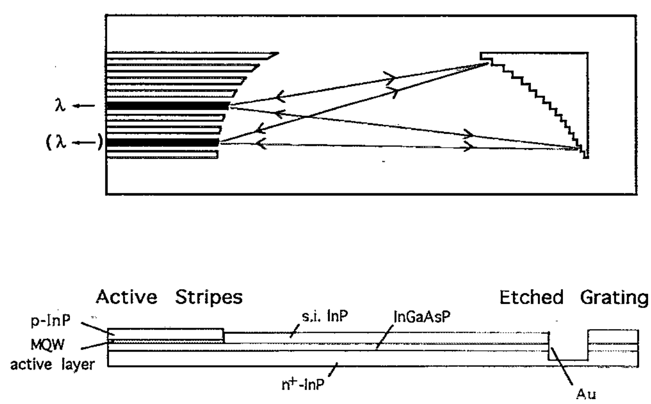

FIG. 1. Diagram of the multistripe array grating integrated cavity (MAGIC) laser.

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multiplexer/demultiplexer.[9] A planar InP/InGaAsP/InP waveguide forms the body of the device. Etched in this is a focusing diffraction grating. In the MAGIC laser this structure is now monolithically integrated with an array of multiquantum well (MQW) active stripes (see Fig. 1). A standard Rowland circle configuration is used for the curved diffraction grating, and implemented in the retro-diffractive Eagle geometry—the etched grating retrodiffracts the light emerging from the end of a pumped stripe, dispersing and focusing it onto the line-segment formed by the same stripe ends, as these lie on the Rowland circle of the grating.

The laser was grown on a (100) n^+-InP substrate by low pressure (76 Torr) organometallic chemical vapor deposition (OMCVD) at 620 °C in a two stage growth process. First, the waveguide core and active stripe structure was grown. This comprised an 0.5 μm n^+-InP buffer layer, followed by a 0.3 μm n-InGaAsP ($n\sim1\times10^{17}$ cm^{-3}, $\lambda_g=1.3$ μm) guide core, an undoped active multi-quantum well (MQW) region consisting of 6 wells of InGaAs and 6 InGaAsP ($\lambda_g=1.3$ μm) barriers, 0.2 μm of quaternary grading, 0.9 μm p-InP ($n\sim1$–7×10^{17}), and finally a 0.2 μm p^+-InGaAsP ($\lambda_g=1.3$ μm) contact layer. Stripes running along $[1\bar{1}0]$ were then delineated using a SiO_2 mask and formed by first dry, and then wet-chemical, etching down to the waveguide core; a thin layer of n-InP grown directly on the guide core provided an etch stop layer for the final chemical etchant; 1:1:8, H_3PO_4:H_2O_2:H_2O. The masked substrate was then returned to the OMCVD reactor and 1.0 μm of semi-insulating Fe:InP was grown to provide current blocking around the stripes; this layer also provided an upper cladding layer for the planar waveguide. It is seen that the MQW active layers of the stripes are formed on top the waveguide core. This arrangement permits good overlap between the optical modes in the active stripes and the planar guide, and does not compromise the optical confinement in the active region.[10]

The diffraction grating was then formed using a SiO_2 etch mask by chemically assisted ion beam etching (CAIBE) with 1500 V Xe^+ ions and a Cl_2 reactive flux.[11] Etch rates were $\sim$0.5 μm/min and good verticality was achieved for the $\sim$3 μm deep grating wall. Angle evaporation of Ti(110 Å)/Au (3000 Å) onto the vertical face of the grating then provided a highly reflective surface. Following standard p-metallization of the stripes with Ti(200 Å)/Au(8000 Å), substrate thinning and backside n-metallization with Ni(100 Å)/Ge(350 Å)/Au(500 Å)/Ni(350 Å)/Au(2000 Å), the chip was cleaved across the stripe array to provide the laser output facet. The contacts were not annealed.

The fabricated laser chip was $\sim$14 mm$\times$3 mm. The active stripes were cleaved to $\sim$2 mm, had a width of 6–7 μm, and an array spacing of $\sim$40 μm, their exact position being determined in order to obtain linearity of output wavelength. The separation between the stripes and the grating was 10 mm. The etched grating was an high order (16th) echelle grating with a d-spacing of $\sim$4.5 μm in a 9 mm radius Rowland circle construction, and was blazed

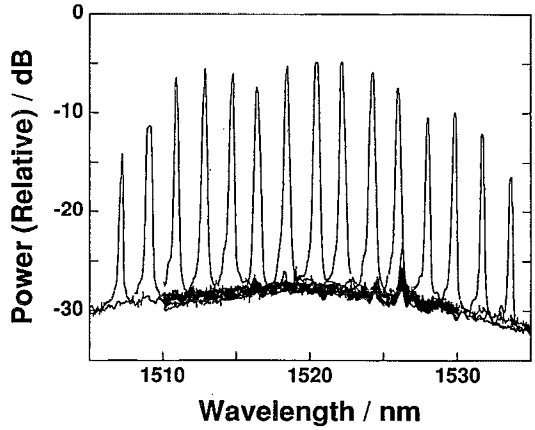

FIG. 2. Laser emission at different wavelengths from a single output stripe when different "second" stripes are pumped. Taken with a 0.1 nm resolution optical spectrum analyzer, with an output stripe bias of 215 nm and second stripe currents of 140 mA.

for retrodiffraction. The laser was examined in pulsed operation and without temperature stabilization.

When one stripe was injection pumped, lasing occurred at a wavelength corresponding to the retrodiffraction of light back from the grating to that stripe. Different stripes lased at different wavelengths in accord with their position relative to the grating. This mode of operation, which is similar to that of a conventional external grating laser, has already been discussed.[5,6]

In this letter we report for the first time *single-output/selectable-wavelength* operation obtained by biasing a single "output" stripe and injection pumping different second stripes in order to obtain lasing at different wavelengths.

The output stripe bias was held constant at 215 mA. An injection current of 70–100 mA into a second stripe was then required to obtain lasing. A higher output stripe bias current required a lower second stripe threshold current, and visa-versa—within modest limits. The total threshold current was a near-constant value of 285–315 mA, corresponding to an injection density of $\sim$1.0 kA/cm^2.

Lasing was obtained at 15 discrete wavelengths, from $\sim$1507 to 1535 nm. The output spectra, taken with a 0.1 nm resolution optical spectrum analyzer, are compiled in Fig. 2.

Lasing intensities were typically 20–25 above the background spontaneous emission. Examination with a scanning Fabry–Perot interferometer revealed that lasing occurred predominantly on a single longitudinal mode at the center of 8–10 longitudinal modes (spacing, $\sim$0.03 nm) with $\sim$10 dB side-mode suppression, increasing to $\sim$20 dB for the more distant modes. The number of longitudinal modes supported is in line with expectations arising from modal calculations.

An examination of the near-field output suggested that up to 3 lateral modes were contributing to the emission. Although up to 7 modes could be supported by the structure, weaker planar guide/stripe coupling, lower gain, and greater loss, inhibits lasing on the higher modes. Constricting the width of the active layer from $\sim$7 to $\sim$1 μm would

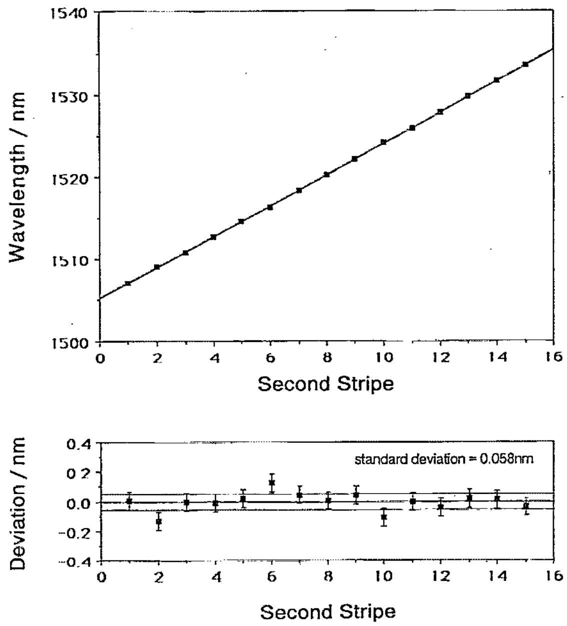

FIG. 3. Upper graph: wavelengths of the laser emissions shown in Fig. 2. Lower graph: measured wavelengths, with reference to a linear wavelength spacing.

be expected to result in both single longitudinal and lateral mode operation. A lower threshold current would also be expected.

The laser wavelengths are plotted in Fig. 3 (upper graph). The wavelength placings were within 3 nm of their original design value. Wavelength accuracy is one of the most attractive features of the MAGIC laser, and arises because the laser wavelength depends only on the geometry and refractive index of the resonant cavity. The physical dimensions of the device can be accurately controlled and an examination of the control of the layer thicknesses and composition of the planar cavity material suggests that laser wavelengths with routine control of better than ± 2 nm should be possible.

The measured laser wavelength spacings were 1.89 nm, with no measurable deviation from linearity. Wavelength values, as obtained from a single scan of a 0.1 nm resolution optical spectrum analyzer, are plotted in Fig. 3 (lower graph). The standard deviation of the measured values from an assumed linear spacing is just ± 0.058 nm, or ~ 3 parts in 100 of the wavelength interval. Although approaching the limit of measurement, these small individual variations are believed to be real and to arise from competition between the central lasing longitudinal modes (separation, 0.03 nm) and submicron differences in the fabrication of one stripe from the next (focal dispersion, ~ 0.1 nm/μm), along with uncontrolled temperature fluctuations (0.2 nm/°C variation expected from the temperature dependence of the planar cavity effective index). If the active stripe width is constricted to permit only single mode operation, even higher spacing accuracy might be obtained.

Finally, we note that changing the laser temperature allows one to sweep the comb of laser wavelengths and fine tune them to the desired values in a WDM network. The effect of temperature on the wavelength spacing is, however, negligible.

In summary, we have demonstrated *single-output/addressable-wavelength* operation of a MAGIC laser. In the device reported, lasing was obtained at 15 accurately set wavelengths in the 1.5 μm fiber band. The precise predetermination of the laser wavelengths, together with the ease of manufacture of the MAGIC laser, suggest that it is highly suited for WDM networks.

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