spectra contain filtered spontaneous emission with enhanced intensity at resonance.

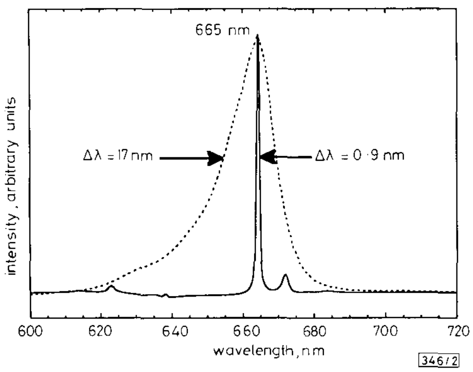

Fig. 2 *Normalised electroluminescence spectra of LED, and of RCLED with 30 coupling DBR periods*

Spectra are collected by a ×10 lens with numerical aperture of 0·21; results taken at room temperature
——— RCLED
······· LED

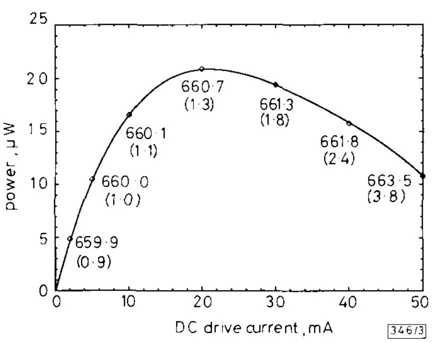

Fig. 3 *Light intensity against drive current for typical 10 μm diameter RCLED device*

——— measured data
◇ peak output wavelength [nm], and linewidth [nm] (in parenthesis) at several points

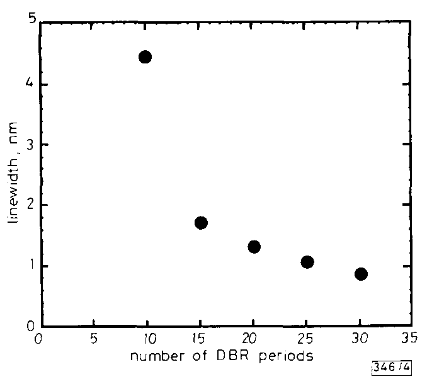

Fig. 4 *Linewidth against number of DBR periods for RCLED*

Room temperature, $\lambda_{peak} \simeq 660$ nm, 20 mA CW

Summary and conclusions: We have reported the first visible RCLEDs. Very narrow linewidths of 0·9–4·5 nm were obtained by changing the cavity Q. Diodes with shorter output wavelengths should also be possible by varying the InAlGaP composition in the active region and by adjusting the AlGaAs DBRs.

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NEW SIMULATED CORRUGATED SCATTERING SURFACE GIVING WIDEBAND CHARACTERISTICS

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Indexing terms: Scattering, Radar cross-section

Simultaneous elimination of specular reflection and backscattered power from a plane metallic surface by simulated corrugated surfaces of constant period and variable strip width for TM polarisation is reported. This new configuration offers almost a ten-fold frequency bandwidth compared with a regularly spaced strip grating of the same size.

Introduction: Recently, a number of papers have appeared in the literature for the elimination of specular reflection from metallic surfaces [1–3]. Simulated corrugated surfaces (SCSs) have been designed and tested successfully for the reduction of the radar cross-section (RCS) of planar surfaces [4, 5]. SCSs are reflector-backed strip gratings on a dielectric substrate with regular period. In all types of SCS, the elimination of specularly reflected power is achieved by enhancement of the backscattered power in that angle. Simultaneous elimination of reflected as well as backscattered power by such gratings has not been reported so far. In this Letter, the development of a novel SCS grating with constant period and variable strip width, which can eliminate specular reflection and backscattering simultaneously, is presented.

Methodology and experimental results: A plane wave incident on a periodic surface excites a discrete spectrum of scattered plane waves. For maximum constructive interference from adjacent strips of period d the angle of diffraction θ_n is related to angle of incidence θ_i by the relation

$$\sin\theta_n = \sin\theta_i + n\lambda/d \qquad n = 0, \pm 1, \ldots$$

where n is the spectral order and λ is the free space wavelength. For periods in the range $\lambda/2 < d < 3\lambda/2$, only specular reflection ($n = 0$) and backscatter ($n = -1$) occur. For perfect blazing, the period must satisfy the Bragg condition

$$kd \sin\theta_i = p\pi \qquad p = 1, 2, \ldots$$

where k is the propagation constant.

SCSs are made by etching thin metallic strips on a reflector-backed dielectric substrate ($\varepsilon_r = 2{\cdot}56$) with period $d = a + b$ kept constant and the width of the strip a varied in geometric progression (GP). The common factor r is selected in such a way that the value of a lies in the range $0 < a < d$.

Diffraction measurements are made in the X-band for TM polarisation using the magic tee analogue cancellation method. The target is placed at the centre of an arch in which the receiving antenna can be rotated. The reflected power from the target is analysed using a measuring amplifier and compared with that from a plane metallic surface.

Fig. 1 shows the typical variation of relative reflected power and relative backscattered power with angle of incidence for

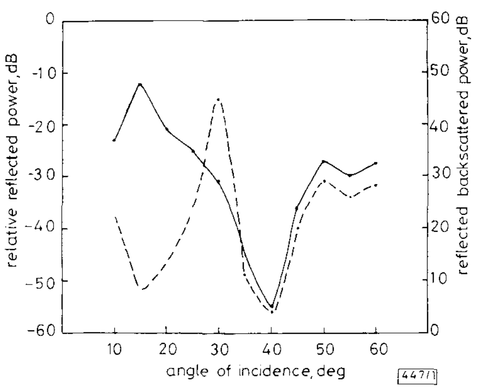

Fig. 1 *Variation of relative reflected power and backscattered power with angle of incidence*

——— relative reflected power
------- backscattered power

the surface having an r value 1·08 and $h/\lambda = 0{\cdot}13$, where h is the dielectric thickness. Specular reflection as well as backscattering is completely eliminated at an angle of incidence 40°. At this angle of incidence, power is scattered to 50 and −20° from the normal. The above observation is confirmed from Fig. 2, which shows the variation of scattered power with receiving angle. A typical variation of relative reflected power with h/λ is shown in Fig. 3. From this graph it is clear that the reflected power is negligible when the dielectric thickness is $0{\cdot}13\,\lambda$.

Fig. 4 shows the variation of relative reflected power with frequency for a progressively varied SCS grating and ordinary SCS grating. The reflected power is below −40 dB over a frequency band of 1·54 GHz for a progressively varied SCS grating, whereas the surface having strips of equal width only has a bandwidth of 0·142 GHz.

Table 1 presents the value of strip width a of the first strip, the common factor r with which strip width increases, angle θ at which specular reflection is suppressed, dielectric thickness h/λ and frequency bandwidth where the reflected power is less than −40 dB.

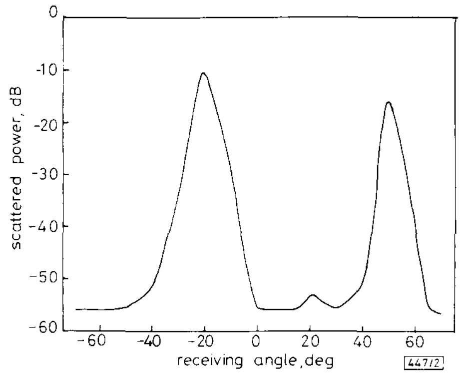

Fig. 2 *Variation of scattered power with receiving angle*

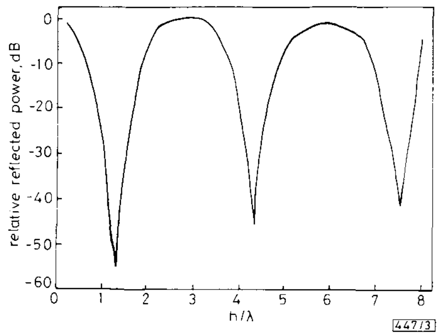

Fig. 3 *Variation of relative reflected power with dielectric thickness*

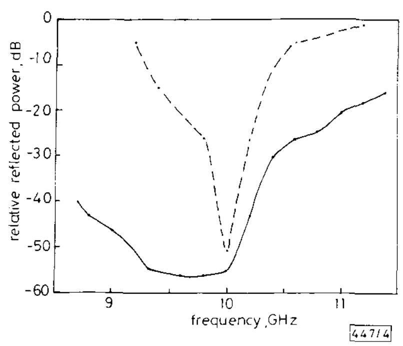

Fig. 4 *Variation of relative reflected power with frequency*

——— $r = 1{\cdot}08$
------- $r = 1$

Table 1 PARAMETERS OF VARIOUS STRIP GRATINGS USED IN THE STUDY

a/λ	r	θ	h/λ	Bandwidth
				GHz
0·500	1·0000	30·0	0·103	0·142
0·433	1·0320	37·5	0·107	0·199
0·333	1·0800	40·0	0·130	1·540
0·300	1·0980	40·0	0·130	0·826
0·250	1·1298	40·0	0·130	1·375
0·233	1·1410	40·0	0·130	1·212
0·200	1·1665	37·5	0·130	1·200
0·166	1·1960	35·0	0·130	1·083
0·100	1·2760	22·5	0·130	1·450

Conclusions: By using SCS gratings with strip width varying in GP, the backscattered power and specularly reflected power from a plane metallic surface can be simultaneously reduced for a particular angle of incidence. This is not possible with a strip grating of equal width and regular period. The broadband property of this surface is useful in RCS reduction techniques.

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THRESHOLD REDUCTION OF 1·3 μm GaInAsP/InP SURFACE EMITTING LASER BY A MASKLESS CIRCULAR PLANAR BURIED HETEROSTRUCTURE REGROWTH

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Indexing terms: Semiconductor lasers, Lasers

A newly introduced maskless planar buried heterostructure regrowth has substantially improved the regrown heterointerface of a 1·3 μm GaInAsP/InP circular buried heterostructure surface emitting laser. The threshold current of the 12 μmϕ device was reduced to 2·2 mA at 77 K under CW conditions.

GaInAsP/InP vertical cavity surface emitting lasers (SELDs) are attracting much interest owing to their potential in future optical fibre communication systems and optical interconnects. Recently, several authors reported the high performance pulsed operation of GaInAsP/InP SELDs using several device structures [1–4]. However, most of them did not satisfy the condition of room temperature CW operation, i.e. a low threshold current, low device resistance, and effective heatsinking. We believe that the buried heterostructure (BH) will be the best structure for satisfying these requirements, when we consider that most practically applied GaInAsP lasers employ the BH configuration.

Previously, we reported a BH device structure called the FCBH-SELD fabricated by two-step LPE regrowth [5]. Although it recorded a low threshold (4·2 mA) at 77 K, there still remains the problem of the relatively defective heterointerface which is recognised as pinholes around the mesa after the regrowth and the significant leakage current in the I–V characteristic. This seems to be caused by the difficulty of burying a circular mesa; the second regrowth does not occur on the (111)-A plane which is likely to appear around the mesa after the first regrowth. In this study, we introduce a single step maskless planar buried heterostructure (PBH) LPE regrowth [6] to overcome this problem. We have improved the heterointerface quality of the GaInAsP/InP circular BH structure and demonstrated a low threshold 1·3 μm BH SELD using this technique. We call this type of device a circular PBH surface emitting laser (CPBH-SELD).

Our device structure is shown in Fig. 1. To achieve efficient carrier confinement and heatsinking, its circular active region

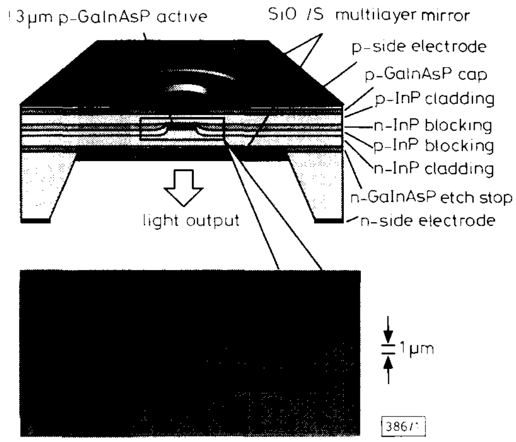

Fig. 1 *Schematic of GaInAsP/InP CPBH-SELD and cross-sectional view of grown structure cleaved near centre of circular active region*

The photograph includes an etch stop layer which will be removed in the fabrication process

is buried by *p*- and *n*-InP blocking layers and additionally covered with a *p*-InP cladding layer. Owing to an almost planarised epitaxial surface, we can also expect high reflectivity of the laser mirror formed on it. As the laser mirror, we adopted an SiO_2/Si dielectric multilayer reflector which provides a satisfactory high reflectivity of >99%.

As a preliminary experiment of PBH regrowth, we examined the growth rate on the top of the etched circular mesa. We prepared a DH wafer having 1 μm thick *n*-GaInAsP etch stop layer, 2 μm *n*-InP, 0·7 μm *p*-GaInAsP active layer, and 0·3 μm *p*-InP grown on (100) *n*-InP substrate. We chemically etched the wafer using KKI etchant ($CH_3COOH : HCl : H_2O_2 = 2:1:1$) and an SiO_2 dot mask to form a circular mesa 2 μm in height. After removing the SiO_2 mask, the blocking layers (each of them 1 μm thick), *p*-InP cladding layer, and p^+-GaInAsP cap layer are successively grown by LPE without a meltback process. From directly observing the cross-section of the grown structure by cleaving near the circular mesa, we confirmed that blocking layers do not grow on the mesa if it is less than 12 μm in diameter. It should be noted that most of the pinholes around the mesa, which were often observed in our previous work, disappeared in this regrowth process. This seems to be attributed to the single step PBH regrowth that suppresses the appearance of the (111)-A plane. As can be seen from Fig. 2,

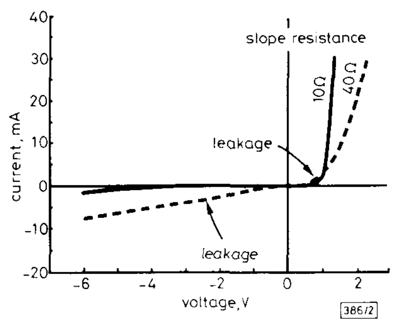

Fig. 2 *Typical current–voltage characteristics of FCBH SELD and CPBH SELD*

RT, CW
——— CPBH
- - - - FCBH