epitaxy (MBE). The cavity design had two focal points, one on the gain structure and the other one on the SESAM. The beam diameter on the gain structure was ~200 µm while it was significantly smaller (~18 µm) on the SESAM. The output coupler had a transmission of 1.5%.

Results: A slowly scanning autocorrelator with lock-in amplification was used to measure the pulse shape (Fig. 2). The autocorrelation was recorded for a maximum output power of 213 mW, showing that the pulses have a Gaussian shape and are free of any pedestals down to −30 dBc. The optical bandwidth (inset of Fig. 2) was ~0.5 nm, close to the transform limit for Gaussian pulses. The peak power was 30 W. The pulse duration as well as the stability of the modelocking was strongly dependent on the cavity setup. We observed that the pulses became shorter when the mode size on the SESAM was reduced, while the mode size on the gain structure was kept constant [12].

With photoluminescence microscopy we detected dark line defects in the gain structure. This might explain the low efficiency of ~10% for continuous wave operation, and its observed degradation: the output power significantly degrades within a few hours. With refined designs (e.g. including strain compensation for the quantum wells) we expect further substantial improvements.

Conclusion: We have demonstrated what is to our knowledge the highest power directly from a passively modelocked semiconductor laser oscillator. It is based on a vertical-external-cavity surface-emitting laser passively modelocked with an SESAM. We obtained 213 mW with 3.2 ps pulses at a repetition rate of 2.06 GHz. The basis for this performance is the gain structure design, which allows for low thermal impedance and a smooth gain spectrum. We believe that such lasers will soon deliver multi-watt average powers at several GHz repetition rates.

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Study of effect of aging on transparent current stability of semiconductor lasers

San-Liang Lee and Yu-Yi Hsu

Wavelength sensing using the wavelength-dependent transparency of laser diodes requires long-term stability of the transparent current. An accelerated aging test has been performed that demonstrates that the transparent current becomes stable over a wide range of wavelengths after 300 h of aging.

Introduction: A direct-bandgap semiconductor optoelectronic device is operated at its transparent condition when its material gain is zero. This unique property is strongly correlated with the characteristics of semiconductor lasers and amplifiers, such as the threshold current, thermal effects, and gain. Many research groups have made great efforts towards investigating the transparent properties for achieving low threshold current or reducing the thermal effects of laser diodes [1, 2]. The transparent condition is also important for operating a semiconductor optical amplifier as a low-crosstalk gate switch [3] or for achieving fast response and high saturation power with optical speed-up at transparency [4]. Besides, the wavelength dependency of the transparency can be exploited for wavelength sensing or monitoring [5, 6].

One critical concern of the transparent property for the above applications is the long-term stability. The most problematic situation relates to wavelength-sensing applications. To obtain a wavelength accuracy of 0.01 nm around the 1.55 µm fibre window, wavelength discrimination by detecting the transparent current would need a current accuracy of 100 ppm [6]. Such current accuracy imposes a critical requirement on the reliability of the transparent current. In this Letter, we report the results of accelerated aging tests on commercial laser diodes and investigate how the transparent current changes as a result of aging.

Experiment: To investigate the wavelength dependency of the transparency stability, the transparent current was measured with detection of the induced voltage across the diode junction, in response to input-modulated light signals [5, 6]. This technique requires stable optical coupling, so the measurements were carried out with pigtailed lasers to eliminate time-consuming optical coupling. Four Fabry-Perot (FP) lasers from the same vendor were tested at 85°C with an injection current of 150 mA, which is about one order higher than the transparent current. The transparent current was measured at 25°C after each aging period. For the experiment, a high-performance tunable laser with optical modulation was used as the probe signal, and the induced voltage across the diode junction was measured with a lockin amplifier. The modulation frequency was 1 kHz. Owing to the fact that the transparent current depends on the input polarisation, a polarisation controller was placed between the tunable laser and the diode laser under test. The transparent current corresponds to the bias current where the induced voltage vanishes, and it can be measured to a resolution of 0.01 mA with a low-noise current source.

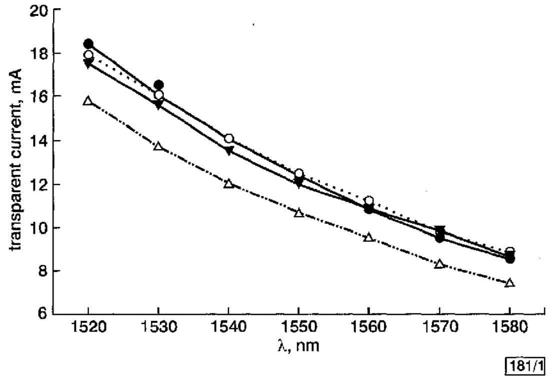

Fig. 1 *Wavelength dependent transparent current for lasers before aging test*

—●— laser 1
····○···· laser 2
—▼— laser 3
—··△··— laser 4

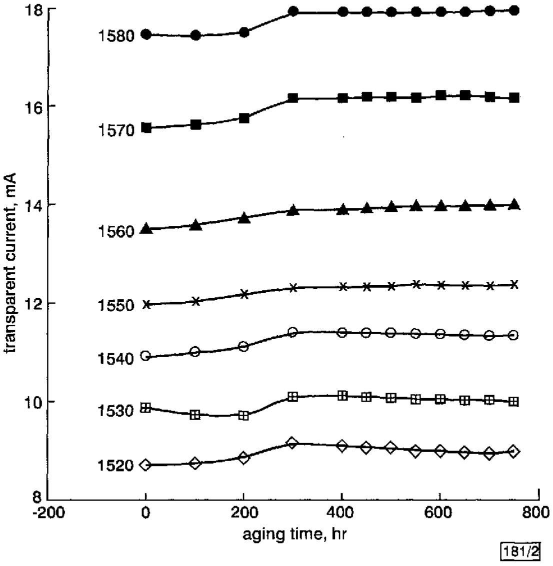

Fig. 2 *Transparent current variation during aging for laser 3*

Results: Fig. 1 shows the transparent current before aging test for the four lasers over a wavelength range from 1520 to 1580 nm. The transparent characteristics are similar except that the transparent current of laser 4 is considerably lower. After accelerated aging, all lasers show apparent drift in the transparent current over the first 300 h. The transparent current remains almost fixed after 300 h. Fig. 2 depicts the evolution of transparent current against aging time observed at different wavelengths for laser 3. All the wavelength channels show a very similar tendency in terms of transparent current variation. To compare the difference between the lasers, the drift in the transparent current of a laser is represented by averaging the drift over all the wavelengths. The average wavelength drift is summarised in Fig. 3. Lasers 1 and 2 show relatively small wavelength drift and their transparent conditions also become stable after ~300 h of aging. This aging characteristic is similar to the results observed in the aging analysis of DBR lasers [7]. Since the transparent current is much smaller than the aging current, these data indicate that sufficient stability for wavelength sensing can be generated by resolving the transparent current if the sensors first pass several hundred hours of burn-in test.

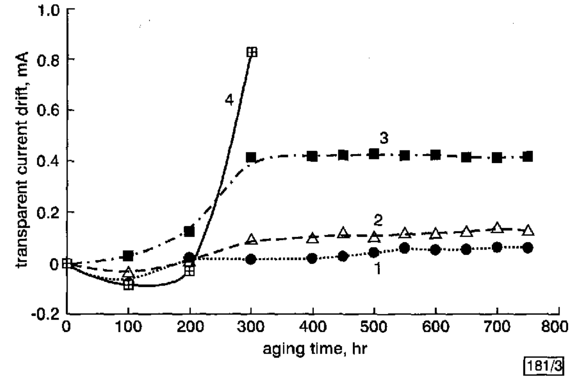

Fig. 3 *Comparison of average transparent current drift among lasers*

The aging of laser 4 results in a significant increase in the transparent current for all wavelengths, in spite of the relatively low transparency before aging. The increase in transparent current is accompanied by an obvious rise in the threshold current and decrease in the output power. This result suggests that the performance degradation of this laser is most likely due to the increase in the non-radiative recombination or leakage current. Facet degradation alone will not change the transparent current.

All the wavelengths show the same stability against aging time but a slightly different amount of transparency drift after 750 h of accelerated aging. Further analysis of the aging test data, as shown in Fig. 4, reveals that the transparent current drift shows resonance-like variation with wavelength. This can be attributed to the effect of the FP resonance of the laser diode on the measurement of the transparent current. Such an effect arises from the slight dependence of the transparent current on the input light power due to free-carrier absorption and nonuniform carrier distribution [6]. The drift in the transparent condition during aging leads to a shift in the resonant wavelength of the FP cavity because of the change in the refractive index for a fixed bias current. This changes the light intensity inside the cavity for a given wavelength. Thus, the amount of transparency drift depends on the relative position of the incident wavelength with respect to the resonant peak. Such resonance-like variation can be eliminated when the facets are coated with antireflection film.

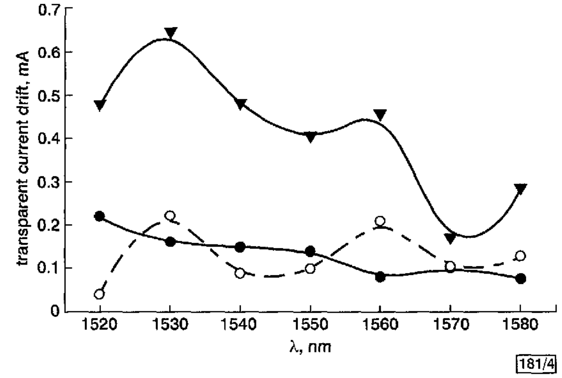

Fig. 4 *Transparent current drift against wavelength*

—●— laser 1
– ○ – laser 2
—▼— laser 3

Conclusion: The results of reliability tests indicate that the transparent current of laser diodes becomes stable after 300 h of burn-in test. Although the transparent current drift is slightly different for different wavelengths, good transparency stability can be observed for a wide range of wavelengths. This result is important for applying wavelength-dependent transparent current in wavelength sensing and monitoring.

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Efficiency improvement of broadband microwave amplifiers using current sharing concept

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The authors present experimental results of a 2 to 18 GHz high-gain dual-stage feedback amplifier employing a novel concept of current sharing that drastically reduces the current consumption by 50% without compromising the amplifier performance and hence produces a more than two-fold improvement in the power-added efficiency.

Introduction: The relentless drive to increase the packaging density of microwave sub-systems and hence the reduction in the sub-system size inevitably puts great demand on the miniaturisation of components and devices that are employed in the sub-system realisation. This demand also, however, puts severe constraint on the current consumption requirements in order to minimise the power dissipation of the components and devices. Amplifier devices employed in microwave sub-systems are the major source of current consumption and, hence, power dissipation. Reduction in the power dissipation of such devices is essential to minimise adverse thermal affects and hence provide significant improvement in system reliability.

In this Letter, the concept of current sharing is introduced and applied to a dual-stage feedback amplifier that is employed in the realisation of high-gain broadband feedback amplifiers operating across the 2 to 18 GHz frequency range. This device is employed in highly demanding systems such as electronic warfare systems. The DC bias arrangement conventionally employed in broadband amplifier designs results in poor efficiency performance due to excessive current consumption. In this Letter, it is demonstrated that a novel current sharing concept can be successfully implemented onto a dual-stage broadband feedback amplifier to realise a substantial reduction in current consumption and an improvement in the efficiency performance. For comparative purposes, an identical specification broadband amplifier was designed and fabricated using a conventional biasing technique.

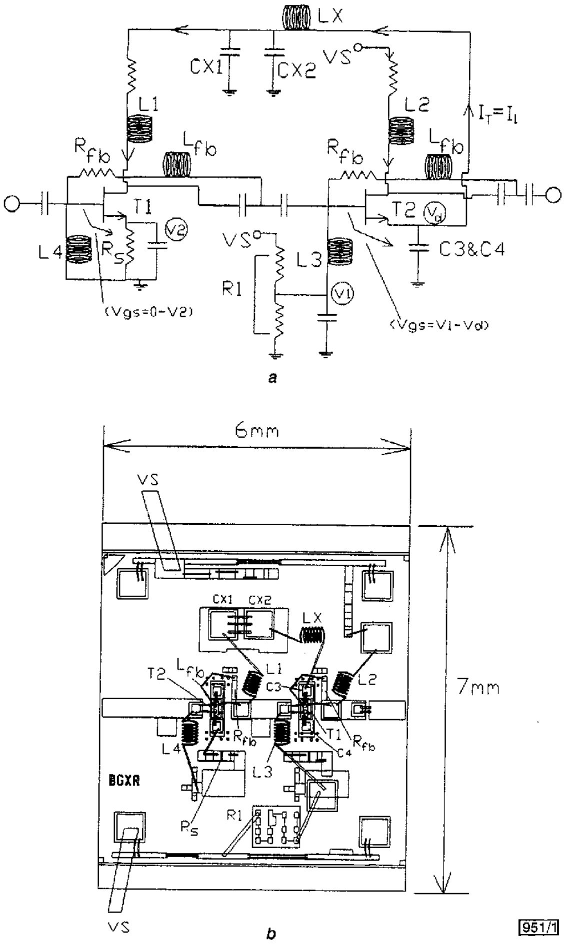

Fig. 1 *2–18 GHz two-stage feedback amplifier in current sharing mode*

a Schematic diagram
b Layout

Current sharing concept: In conventional feedback amplifiers, the DC bias [1] is applied using the technique of 'self-bias'. The advantage of this biasing technique is that the devices can be operated from a single positive supply without the need to have a sequencing circuit [2] that provides separate gate and drain bias. However, the major problem associated with amplifier designs using this type of biasing mode is that each active device requires a separate biasing network, hence an increased current requirement.

In this Letter, an alternative technique is introduced that employs the concept of current sharing, as illustrated in Fig. 1*a*, where the same current drawn by one active device is also used to bias another active device. The total current ($I_T = I_1$) drawn by the dual-stage feedback amplifier is set by the source resistor R_S of the first device T1, which is biased in the self-bias mode. Biasing of the second device T2 (voltage $V1$) is set by the potential divider R1 connected to the gate of device T2. The drain voltage of T2 (voltage V_d) is connected to the source decoupling capacitors C3 and C4, that enables the correct gate-source voltage ($Vgs = V1 - V_d$) to forward bias the device T2. The current flows from VS through T2, T1 and R_S to ground. The supply voltage is used to bias T2, T1 and the potential divider R1. Inductor LX provides RF isolation between the source of device T2 and the drain of device T1. The selection of components C3, C4, CX1, CX2, and the isolating inductor LX are critical in ensuring stable DC operation of the amplifier across the entire (2–18 GHz) multi-octave