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THE EFFECT OF DETUNED WAVELENGTH IN THE DYNAMIC PERFORMANCE OF DISTRIBUTED FEEDBACK LASERS OPERATING AT O BAND AND C BAND

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ABSTRACT *A comparison is presented between the experimental dynamic behaviour of detuned AlInGaAs ridge waveguide distributed feedback lasers operating at O band and C band at two different temperatures. The nominal centre wavelengths at 25 °C for the set of devices studied were 1270 nm, 1310 nm, and 1550 nm. Preliminary static characterisation of the samples showed consistent trends between wavelength detuning, characteristic temperature, and power output. For all set of samples, the characteristic temperature was substantially higher for the samples detuned to longer wavelengths (red) at room temperature. At the temperature of 85 °C, a higher power efficiency was observed for those samples that thermally shifted nearer the peak optical gain. Resonance frequencies were extracted at 25 °C and 85 °C by means of electro-optical transmission measurements and relative intensity noise measurements. The extracted values confirmed that, at room temperature the samples detuned to shorter wavelengths (blue) showed the highest modulation efficiencies. At the temperature of 85 °C, however, the wavelength and optical gain thermal shift makes those same samples to have the lowest resonant frequencies. The dynamic trends over temperature were clearer for the O band set of samples, while the detuning had a less pronounced effect at C band. The range of maximum resonance frequencies studied was from 12 GHz to 14 GHz, which makes the devices suitable for uncooled communication applications at multi-gigabit data rates.*

Key words: Distributed feedback laser, wavelength detuning, dynamics

1. O-Band and C-Band DFB laser design

The work in Ref. [1] described a framework for evaluation of detuned 1310 nm ridge waveguide distributed feedback (DFB) lasers in order to optimize their dynamic performance between the sink temperatures of 25 °C and 85 °C. A similar but extended approach is implemented in the following sections looking to clarify the effect of detuning on laser designs centred around lower O-band wavelengths (1270 nm), and C-band wavelengths (1550 nm). All the lasers studied here have been fabricated using the same process techniques, where a Bragg grating structure is overgrown on an InP based substrate with an AlInGaAs active layer formed by a strained multi-quantum well (MQW) system. The design of the quantum wells in each case is tailored to produce an optical gain output within a required wavelength range. An illustration of the active layers and grating for the laser design is shown in Figure 1. The lasers (for every wavelength) have a cavity length of 250 µm, the same number of quantum wells, and a grating strength determined by the coupling coefficient κL with values of either 1.05 (C-band) or 1.35 (O-band).

Detuning of the DFB laser wavelength is obtained by varying the pitch value (Λ) illustrated in Figure 1. Three different InP wafer lots were grown and processed in order to produce functioning DFB lasers within the required output wavelength ranges. Detuned samples were then assembled for tests from each wafer lot. The samples from the 1310 nm wafer lot have been previously described in Ref. [1]. The detuned 1270 nm and 1550 nm sample set description is presented in Table 1 and Table 2 respectively, with their corresponding detuning pitch Λ and wavelength offset Δ.

The relation between the DFBs lasing wavelength and its peak optical gain is quantified by measuring the thermal spectral drift of Fabry-Pérot (FP) lasers that have been grown and processed simultaneously with the DFB lasers in each of the three studied AlInGaAs epitaxy InP wafers. The FP drift of wavelength versus temperature was measured to be 0.5 nm/°C for the O-band lasers, and 0.6 nm/°C for the C-band lasers. An illustration of the thermal spectral drift for the C-band FP lasers between temperatures of 25 °C and 85 °C is shown in Figure 2. Wavelength detuning Δ is defined as the difference between the DFB optical output spectra and the peak optical gain at the sink temperature (which corresponds to the FP laser peak output). Figure 3 shows, for example, the measured spectral optical output of the four detuned samples from the 1550 nm system at the sink temperature of 25 °C.

2. Effect of wavelength detuning on DFB laser characteristic temperature and maximum power

Before dynamic characterisation of the samples, a preliminary static study of the effect of detuning on threshold current and power was performed. Small populations of detuned lasers were tested between 25 °C and 85 °C in order to determine characteristic temperature and change in output power. For the three different epitaxy wafers grown, the measured characteristic temperature (T_0) showed a very clear trend towards increasing values for red-detuned DFB samples. A plot of the measured T_0 results is shown in Figure 4. The red-detuned parts from the shortest wavelength epitaxy design (1270 nm) showed the highest measured values of T_0, followed by the 1310 nm parts and 1550 nm parts. This points to a reduction of threshold current values that occurs when the lasing wavelength is relatively closer to the peak optical gain at high temperatures. Similarly, DFB detuned parts were tested at 85 °C in order to determine trends in output power. For the case of O-band, the samples showed a very clear trend towards increased output power when the detuning brings the lasing wavelength closer to peak optical gain at high temperature. However, for the case of C-band, the benefit of detuning was much more limited. A plot of the measured power at 85 °C is shown in Figure 5.

The T_0 and output power results plotted in Figure 4 and Figure 5 showed that the O-band lots have a sharper, steeper response to wavelength detuning compared to the C-band lot (e.g. Δ=+18 nm detuning at 25 °C). It is known that laser cavity internal losses (absorption coefficient) are substantially higher for the longer wavelengths [2], and for those lasers (C-band, in this case) it can explain a damping effect on the shape of the optical gain across wavelength. The damping would reduce the laser sensitivity to detuning, given that the optical gain would appear flatter under the chosen values of lasing wavelengths. This is likely to have a significant effect on the lasers differential gain that rules over their dynamic behaviour at room and high temperature. In order to establish the dynamic effect of detuning, the samples in Table 1 and Table 2 were assembled to perform electro-optical transmission (S_{21}) and relative intensity noise (RIN) measurements.

3. DFB laser dynamic characterisation (RIN and S_{21})

Resonance frequency values for each device at different injection currents were extracted by means of numerical fittings of their optoelectronic transmission S_{21} [3] and RIN measurement response. As in the previous sections, the measurements took place at sink temperatures of 25 °C and 85 °C. The testing methodology has been previously described in Ref. [1].

Table 3 summarizes the tests performed in each set of detuned samples for the three different epitaxial system designs (nominal wavelength output), as well as their detuning range Δ. Static and dynamic tests were performed by coupling the light of the DFB lasers to either a network analyser or spectral analyser using a single mode lensed fibre.

A plot of the extracted resonance frequencies versus injection current for each epitaxial system is shown in Figure 6, Figure 7 and Figure 8. For clarity of illustration, only the samples detuned to the shortest and longest wavelength of each epitaxial system are included in the plots. The highest measured resonance frequency values reached 14 GHz for the O-band samples (Figure 6a, Figure 7a). The C-band samples were relatively slower, reaching only 12 GHz (Figure 8a). The difference in speed is attributed to the higher absorption coefficient at longer temperatures [2], and the consequential reduction of differential gain. The differential gain value, as well as the laser cavity volume limit the speed of the device [4].

At the sink temperature of 85 °C, the highest measured resonance frequency (>10 GHz) corresponds to the 1270 nm design blue-detuned and very near its wavelength peak optical gain (Figure 6b). The dynamic trends of the O-band lasers (1270 nm, 1310 nm) are similar in terms of the detuning effect on resonance frequency, showing higher modulation efficiencies for those parts blue-detuned and relatively near their peak optical gain ($|\Delta|<10$ nm). At 85 °C, the drop of speed for the C-band samples shown in Figure 8b was more substantial than the O-band parts, with maximum measured resonance frequencies dropping from 12 GHz to around 6 GHz. As with the O-band samples, blue-detuning near the peak optical gain showed the highest measured resonance frequencies achievable (Δ=-11 nm).

The experiments confirmed that a higher dynamic sensitivity occurs for the detuned samples with the shortest nominal design wavelengths. At 25 °C, modulation efficiencies changed by 31% (from 1.9 GHz/mA$^{0.5}$ to 1.3 GHz/mA$^{0.5}$) for the 1270 nm detuned samples, while it changes only by 14% (from 1.4 GHz/mA$^{0.5}$ to 1.2 GHz/mA$^{0.5}$) for the 1550 nm samples.

4. Conclusion

Wavelength detuned DFB samples at O-band and C-band have been statically and dynamically characterized and their performance has been compared. O band samples working around 1270 nm and 1310 nm showed a higher sensitivity to the implemented detuning compared to the C band lot. Characteristic temperature and maximum power showed notable increases depending on the relative positions of detuned wavelength to peak optical gain. Maximum resonance frequencies were measured at 25 °C and 85 °C corresponding consistently to blue-detuned DFB samples at less than 20 nm range from the device peak optical gain. Frequency response showed that detuned designs are capable of 10 Gbps data transmission at 25 °C, while at 85 °C O-band samples require further optimization. C-band samples suffered from limited bandwidth at 85 °C, with an increase of the optical confinement factor and differential gain being required in order to comply with 10 Gbps uncooled communication applications.

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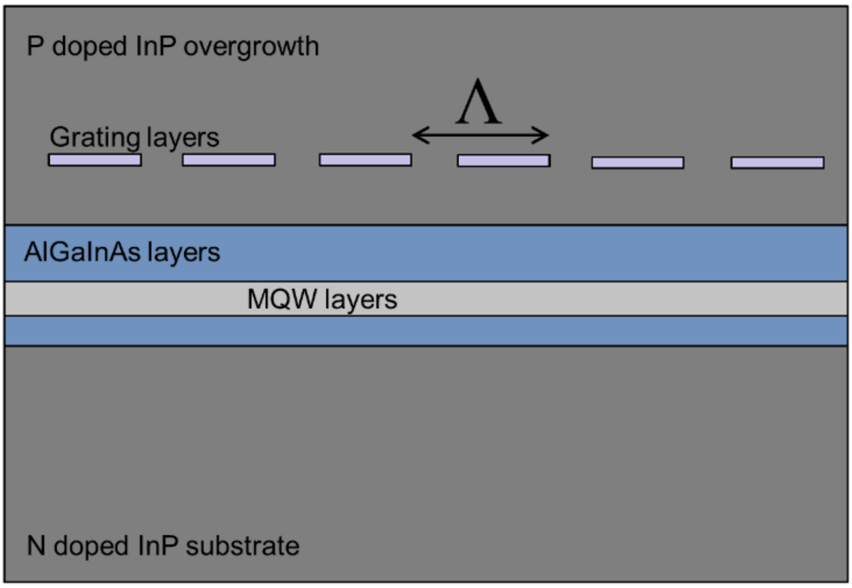


Figure 1 Schematic representation of a DFB laser grating and active layers epitaxy structure

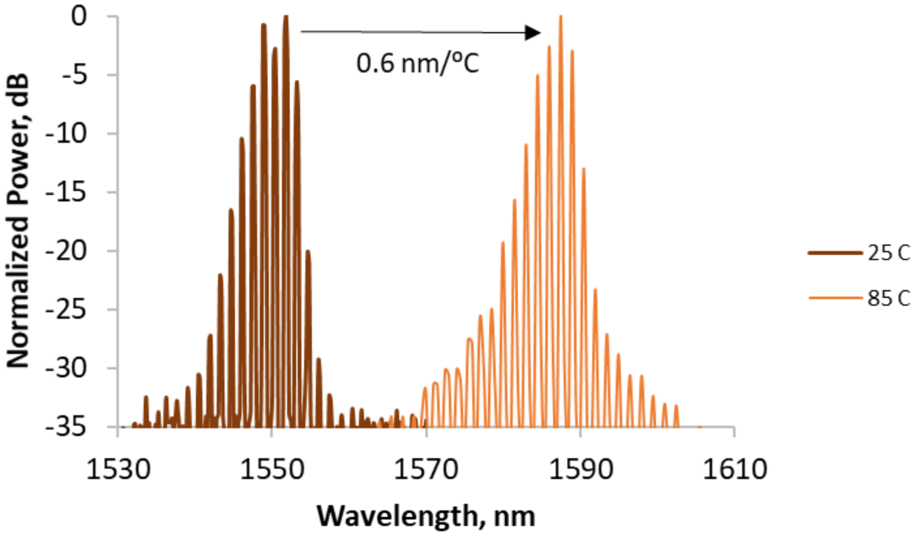


Figure 2 Measured thermal spectral shift of C-band Fabry-Pérot laser

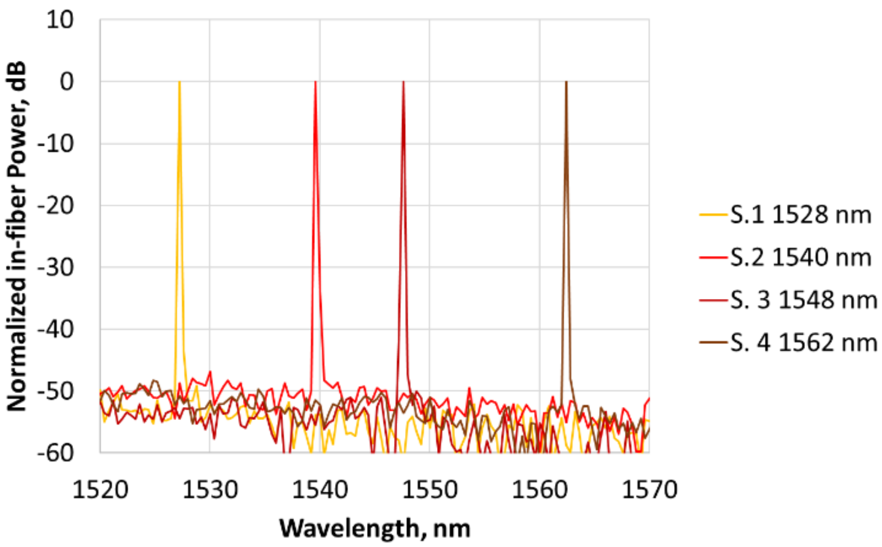


Figure 3 Measurement of the spectral output of DFB samples with detuned wavelengths between 1528 nm and 1562 nm

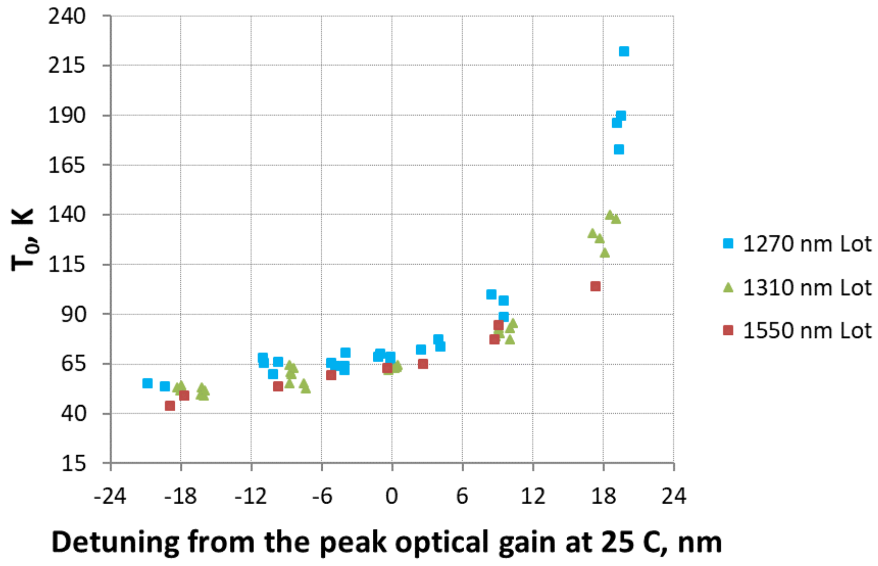


Figure 4 Characteristic temperature of detuned DFB sample populations from three nominal wavelength lots

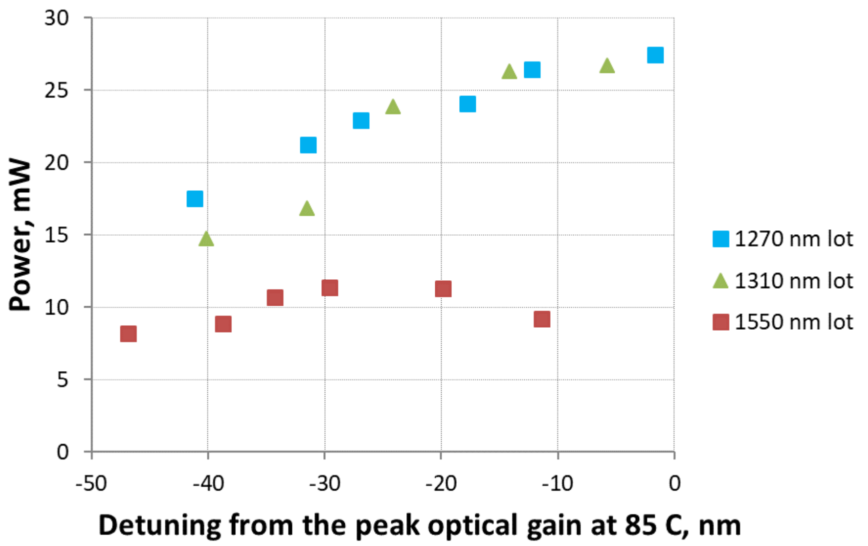
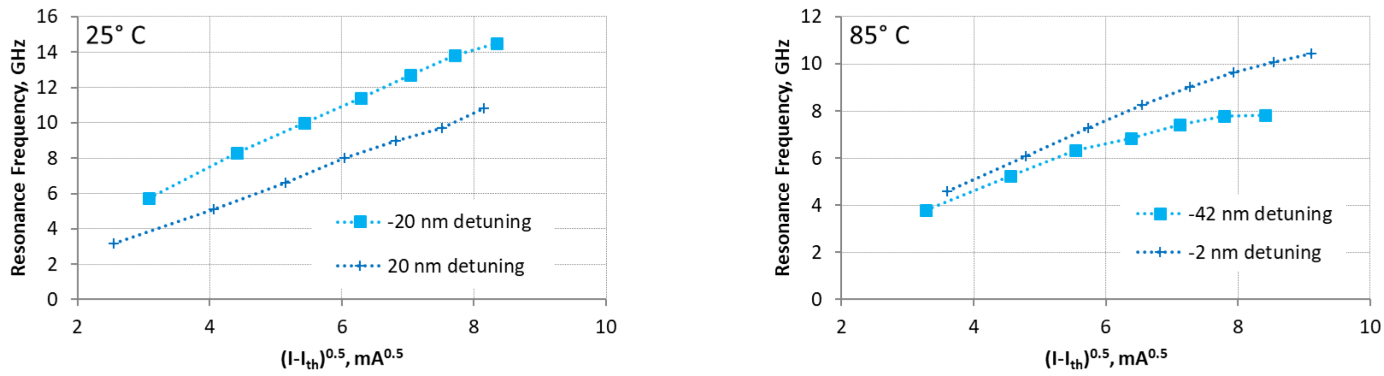
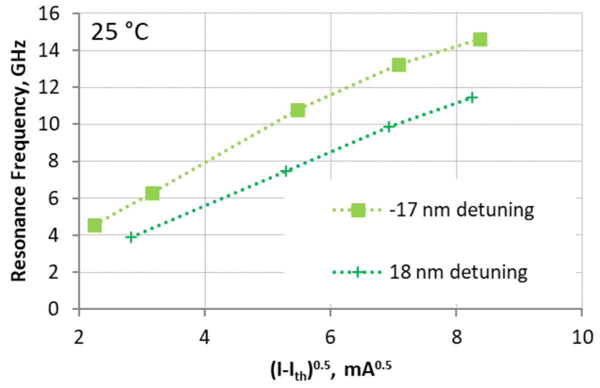


Figure 5 Measured output power at 85 ºC for DFB detuned samples from three nominal wavelength lots

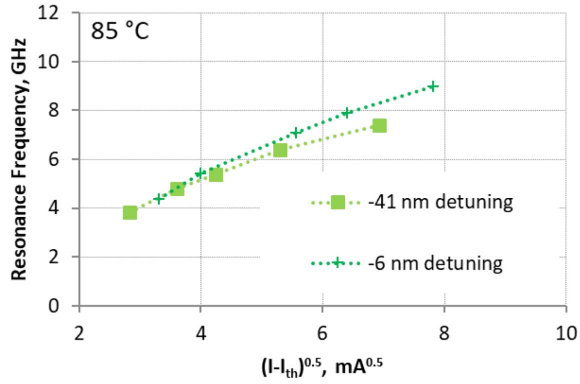


(a) (b)

Figure 6 Measured resonance frequencies of two 1270 nm DFB detuned samples at (a) 25 ºC and (b) 85 ºC

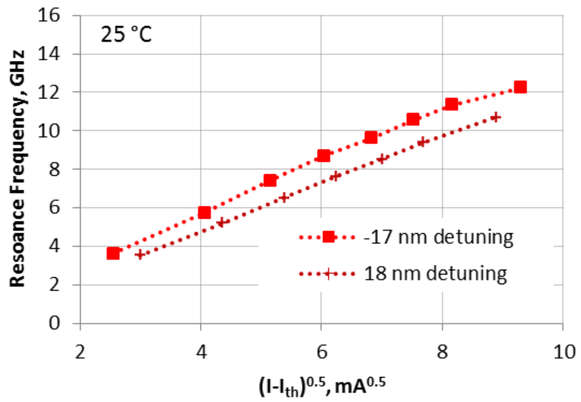


(a)

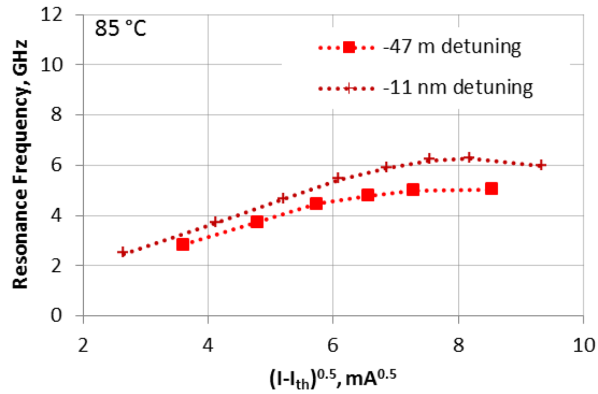


(b)

Figure 7 Measured resonance frequencies of two 1310 nm DFB detuned samples at (a) 25 ºC and (b) 85 ºC



(a)



(b)

Figure 8 Measured resonance frequencies of two 1550 nm DFB detuned samples at (a) 25 ºC and (b) 85 ºC

Table 1 Wavelength (λ), wavelength detuning from peak optical gain (Δ), pitch (Λ), characteristic temperature (T_0), and modulation efficiency (M. E.) of the detuned samples centred around 1270 nm

Sample ID	λ, 25 °C (nm)	λ, 85 °C (nm)	Δ, 25 °C (nm)	Δ, 85 °C (nm)	Λ (nm)	T_0, (K)	M. E., 25 °C (GHz/mA$^{0.5}$)	M. E., 85 °C (GHz/mA$^{0.5}$)
S. 1	1250	1256	-20	-42	192.2	74.7	1.9	0.9
S. 2	1259	1264	-10	-33	193.9	65.3	1.9	1.1
S. 3	1266	1271	-3	-26	194.9	63.76	1.6	1.1
S. 4	1280	1285	11	-12	197.3	88.8	1.4	1.1
S. 5	1289	1295	20	-2	199.1	172.7	1.3	1.3

Table 2 Wavelength (λ), wavelength detuning from peak optical gain (Δ), pitch (Λ), characteristic temperature (T_0), and modulation efficiency (M. E.) of the detuned samples centred around 1550 nm

Sample ID	λ, 25 °C (nm)	λ, 85 °C (nm)	Δ, 25 °C (nm)	Δ, 85 °C (nm)	Λ (nm)	T_0, (K)	M. E., 25 °C (GHz/mA$^{0.5}$)	M. E., 85 °C (GHz/mA$^{0.5}$)
S. 1	1528	1534	-17	-47	240.3	48	1.4	0.8
S. 2	1540	1547	-5	-34	241.9	64	1.4	0.9
S. 3	1548	1554	3	-27	242.8	73	1.4	0.9
S. 4	1562	1569	18	-11	245.0	118	1.2	0.9

Table 3 Summary of the static and dynamic tests performed on the DFB detuned samples

Epitaxy System Wavelength	# Samples	Detuning (Δ) at 25 °C	Dynamics tests at 25 °C, 85 °C	Static tests at 25 °C, 85 °C
1270 nm DFB	5	-20 nm to 20 nm	RIN	LIV, Spectral
1310 nm DFB	5	-17 nm to 18 nm	S_{21}, RIN	LIV. Spectral
1550 nm DFB	4	-17 nm to 18 nm	S_{21}	LIV, Spectral