

# InGaAs/InGaAsP integrated tunable detector grown by chemical beam epitaxy

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By controlling the thickness of the grating depth with chemical beam epitaxy (CBE) growth time, we report in this letter the design and performance of an integrated tunable detector. A carefully designed tunable active filter, which allows only one below threshold Fabry-Perot mode for operation, is integrated with a waveguide detector. The full tuning range of this kind of tunable device can now be utilized for system applications.

Wavelength-division-multiplexed (WDM) transmission is indispensable to fully exploit the potential for very wide bandwidth in future optical fiber communication systems. In a WDM network, a key component in the receiver side is the wavelength demultiplexer. The below threshold biased tunable distributed-Bragg-reflector (DBR) laser has recently been used as a tunable wavelength demultiplexer with the advantages of simple integrated structure, fast center wavelength tuning, and easy filter bandwidth controlling.<sup>1,2</sup> However, some disadvantages have also been observed. First, using the active medium as a detecting medium produces lower quantum efficiency and higher signal distortion.<sup>3</sup> It is necessary to add a quantum detector (instead of Fermi-level detector) to the back of the active filter to separate the detection function and filter function of the device. Second, even though the DBR laser is single mode when biased above threshold, it usually allows more than one Fabry-Perot (FP) mode inside the Bragg reflection band (stop band) of the waveguide grating. Figure 1 shows the below threshold noise spectrum of a typical DBR laser we have been using. When such a device is used for active filtering and amplifying, signals with the same frequencies as other FP modes will also be amplified and make the output very noisy. Even though a DBR laser tuning range of more than 1000 Å has been reported, this problem limits the useful tuning range of the tunable detector to less than one of the FP mode spacing. In order to fully utilize the tuning range of a DBR active filter, a carefully designed device with only one below-threshold FP mode has to be demonstrated.

The longitudinal mode behavior of a DBR laser can be explained as shown in Fig. 2.<sup>4</sup> The lowest threshold (lasing) mode is selected by the Bragg reflection band of the waveguide grating from the equally spaced FP modes which are determined by the total effective cavity length of the DBR laser. In order to achieve the desired characteristics of only one below threshold FP mode in the cavity, we can either reduce the width of the stop band or increase the mode spacing of the FP modes to reject all the other

modes and allow only one possible lasing mode under the Bragg reflection band. The Bragg reflection bandwidth is controlled by the grating coupling constant,  $\kappa$ , which can be calculated according to the formula

$$\kappa = \frac{k_0 \int_a \Delta(n^2(x,z)) |\epsilon|^2 dx}{2\beta \int_{-\infty}^{+\infty} |\epsilon|^2 dx},$$

where  $k_0$  is the wave vector in vacuum.  $\beta$  is the propagation constant,  $n$  is the reflection index, and  $\epsilon$  is the electrical field. The amplitude of  $\kappa$  is almost linearly proportional to the grating depth,  $d$ , when it is small. The larger the overlapping integral of the grating index difference with the mode profile, the larger is the  $\kappa$ . We show in Fig. 3 the relationship between  $\kappa$  and the reflection spectra at different grating lengths. For a strong grating like  $\kappa$  equal to 200  $\text{cm}^{-1}$  the reflection spectra has a broad width and the peak reflectivity saturate very quickly with increasing grating length up to only 200  $\mu\text{m}$  long. The peak reflectivities are less than 100% and this is because that in all the calculation a waveguide loss of 10  $\text{cm}^{-1}$  was assumed. For a weak grating like  $\kappa = 10 \text{ cm}^{-1}$ , even though the band is narrow, to provide a reflectivity of more than 50% requires a grating length of more than several mm long. Controlled by the thickness of the grating layer, the width of the stop band, theoretically, can be reduced to infinitely small. However, due to the increasing absorption loss and the scattering loss from either the roughness of the waveguide sidewall or the nonuniformity of the grating layer with the increasing of

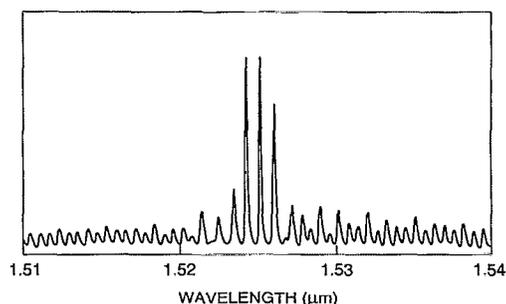


FIG. 1. Output spectrum of a conventional DBR laser when biased below threshold.

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medium, on top of the grating layer, is composed of six 50-Å-thick InGaAs strained quantum wells and six 120 Å 1.25*Q* barriers. Because the thickness of the grating layer is controlled by the CBE growth time, the waveguide grating coupling constant,  $\kappa$ , is also well defined. The device is processed by following standard active-passing etching, grating etching, stripe etching, MOCVD regrowth, and multisection metallization. The completed devices were mounted for characterization and gain measurement. The fabricated devices have laser thresholds around 20 mA when biased above threshold. Some of the lasers has generated record high side-mode suppression ratio of 58.5 dB. The tuning range of the laser is around 32 Å for this batch and can be higher than 90 Å (Ref. 6) if the doping profile and *p-n* junction position is optimized. The below threshold mode behavior is shown in Fig. 5. Both the theoretical and measured spectra show the two side modes are suppressed and cannot grow when bias is increased. A pair of devices with very close output wavelengths were used for on- and off-resonance gain measurement. The device has a normal free-space coupling loss around -8 dB which can be considerably improved when a fiber pigtail is used. The off-resonance coupling loss is around 3 dB, which is a re-

sult of the waveguide and grating scattering losses when the signal pass through the active and the grating section. The measured on-resonance gain is 17 dB at the in-waveguide signal level of -26 dB m and reduces to 5 dB at the level of -10 dB m due to the gain saturation effect.

In conclusion, we have fabricated an integrated tunable detector which allows only one below threshold FP modes for operation. The tuning range of such kind of active filters can be fully utilized. This device will be useful for WDM demultiplexing as well as high speed WDM packet switching.

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