30×100 GHz Digitally Wavelength Switchable V-coupled-cavity Laser with Cleaved Facets

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Abstract— We present some latest results on the V-coupled-cavity laser (VCCL) with cleaved facets. Over 30 channels with 100 GHz spacing and side-mode-suppression-ratio over 30 dB are achieved with single electrode tuning. The fabrication process is the same as that of a Fabry-Perot laser and the device size is only 500 μm × 300 μm.

1. INTRODUCTION

Widely tunable lasers are of vital importance for the modern optical communication systems. With the development of dense wavelength division multiplexing (DWDM) systems, tunable lasers are required to have large wavelength tuning range, large side-mode-suppression-ratio, low cost and low manufacture complexity. Over the decades, many tunable lasers are invented, such as sampled grating distributed Bragg reflector (SGDBR) laser [1], superstructure grating (SSG) DBR laser [2], distributed feedback (DFB) laser array with micro-electro-mechanical system (MEMS) switches [3], wavelength switchable semiconductor laser based on half-wave coupled Fabry-Pérot and rectangular ring resonators [4], and V-coupled-cavity laser with etched facets [5]. However, the former three kinds of lasers not only require complicated fabrication process for gratings, but also use multiple electrodes to control the wavelength tuning effect, which adds to the overall cost. And the latter two lasers require a deep-etch fabrication step to form the reflection facets.

Coupled-cavity lasers with an etched trench or cleaved-coupled-cavity (C^3) structure have been investigated in the 1980's. While the theory of such a coupled-cavity is well established and fabricating it needs no epitaxial regrowth, the SMSR of coupled-cavity laser is very poor (about 20 dB). Recently we developed a simpler design of V-coupled-cavity laser with cleaved facets, emitting 30 channels wavelength with a side-mode-suppression-ratio (SMSR) around 30 dB. Such a simple, compact and high-performance laser is a promising alternative to the existing tunable lasers and has great potential for wide use in optical networks.

2. DEVICE STRUCTURE AND FABRICATION

The V-coupled-cavity laser comprises a fixed gain cavity and a channel selector cavity with different optical path length and a 2×2 half-wave coupler, as shown in Fig. 1. The 2×2 half-wave coupler is designed to have an optimal coupling coefficient to ensure high side-mode suppression ratio (SMSR). Unlike normal multimode interference (MMI), the cross-coupling coefficient of the half-wave coupler has a relative phase of π with respect to self-coupling coefficient. The length of the fixed gain cavity is designed to be 466 μm, so that the resonance frequency spacing is 100 GHz as defined by ITU. The length of the channel selector cavity is 512 μm, a little longer than that of the fixed gain cavity so that the wavelength tuning range can be magnified by the Vernier effect. Three electrodes are deposited on the top surface, and a ground electrode is deposited on the back side. The wavelength tuning is accomplished by changing the current on the electrode of the channel selector cavity.

The principle of digital wavelength tuning is schematically shown in Fig. 2. Δf stands for the frequency interval of resonant modes in the fixed gain cavity, and $\Delta f'$ stands for the frequency interval of resonant modes in the channel selector cavity. The lasing mode occurs at a resonant frequency f_0. By shifting the resonant frequency comb of the channel selector cavity by $|\Delta f - \Delta f'|$, the lasing mode can be swiched to an adjacent mode of the fixed cavity. As a result, the shift of the laser frequency with the averaged effective refractive index change of the channel selector cavity is amplified by a factor of $\Delta f'/|\Delta f - \Delta f'|$ and only a single electrode is required for the wavelength switching. The distance between two aligned resonant peaks are called the free spectral range (FSR) of the coupled-cavity.

A standard ridge waveguide laser structure with InGaAsP/InP multiple quantum wells (MQW) was used to fabricate the laser. The MQW structure was grown by metal-organic chemical vapor deposition. It consists of 0.2 μm Zn-doped In0.53Ga0.47As cap, 1.5 μm Zn-doped InP cladding,

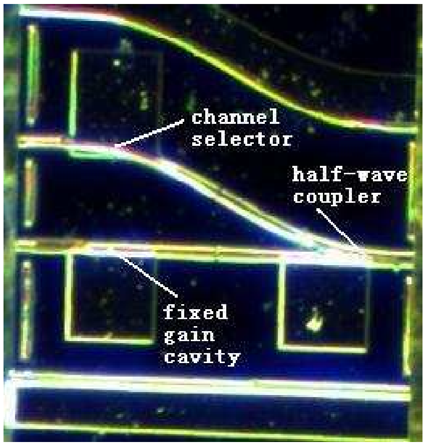

Figure 1: Optical microscope image of the V-coupled-cavity laser.

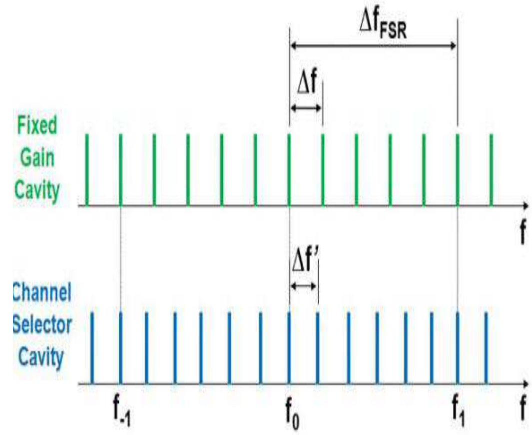

Figure 2: Schematic diagram illustrating the relationships between the resonant frequency combs of the two cavities.

0.004 µm Zn-doped InGaAsP etch-stop layer, 0.15 µm Zn-doped InP cladding, 0.06 µm InGaAsP step-graded index separate confinement layers with the bandgap wavelength λ_g varying from 1.05 µm to 1.25 µm, five repeats of 5.5 nm undoped 1.2% compressively strained InGaAsP quantum well and 10 nm InGaAsP barrier ($\lambda_g = 1.25$ µm), 0.06 µm InGaAsP step-graded index separate confinement layers, and 1.5 µm Si-doped InP buffer on n-doped InP substrate. The measured photoluminescence peak wavelength is at about 1.55 µm. It is an all-active device with no grating or ring resonators, and therefore it does not require any epitaxial regrowth. The fabrication process is similar to simple Fabry-Perot lasers and the device length is less than 0.5 mm.

3. MEASUREMENT RESULTS

The fabrication process is the same as that of a Fabry-Perot laser. First, the wafer was cleaved into bars, then the lasers were tested on an aluminum nitride (AlN) with a thermo-electric cooler (TEC) controlled at 20°C. The currents injected on the half-wave coupler and fixed-gain cavity are 50 mA and 30 mA, respectively. Fig. 3 shows the wavelength of the main mode as a function of the tuning current on the channel selector cavity. When the current on the channel selector increases from 18 mA to 145 mA, the wavelength tuning is about 25 nm and the lasing wavelength is switched digitally over 33 consecutive channels.

Figure 4 shows the spectrum of the laser when the current on the channel selector was 30 mA. It shows a single-mode emission spectrum with SMSR of 33 dB. Fig. 5 shows the overlapped spectra for all of the 30 channels. The SMSR are around 30 dB for all the channels. The SMSR can be further improved by design optimization and fabrication improvement.

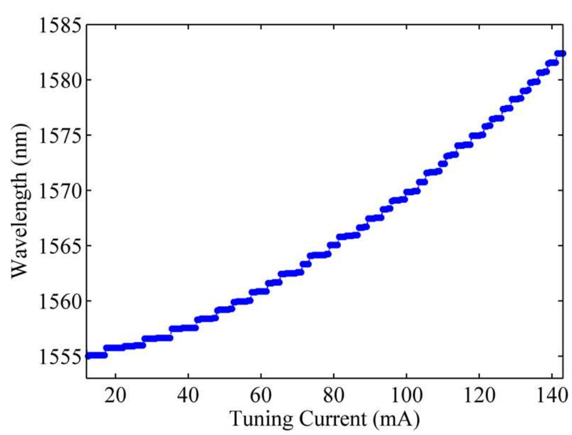

Figure 3: Measured digital wavelength tuning curve.

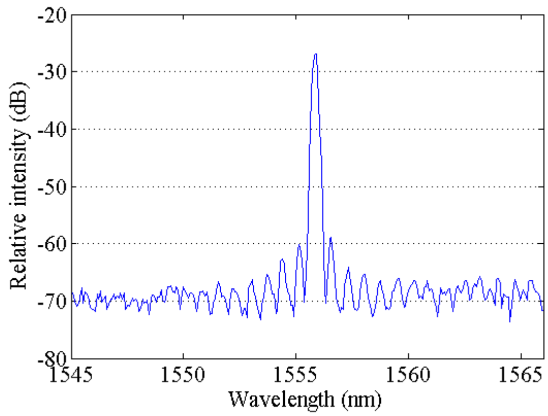

Figure 4: Measured single channel spectrum.

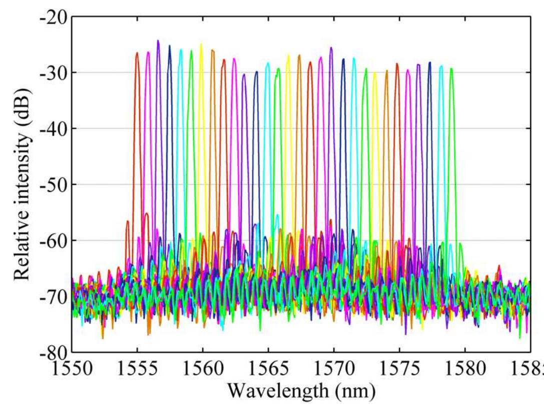

Figure 5: Overlapped 30-channel spectra.

4. CONCLUSIONS

Single-electrode-controlled 30×100 GHz wavelength switchable V-coupled-cavity laser with cleaved facets is demonstrated with a SMSR as high as 30 dB. It is compact, easy to be fabricated, and allows the lasing wavelength to be switched over a wide range with a single electrode control. The fabrication process is exactly the same as that of Fabry-Perot laser, thus it does not require complex gratings, epitaxial regrowth and deep-etched reflection facets. Since the device size is comparable to conventional DFB or Fabry-Perot lasers, it can be easily fit into a small-form-factor package. Because of its advantages, V-coupled-cavity laser with cleaved facets can be used for practical applications in optical networks.

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