# Tuning Extension of a Difference-Frequency Generation up to 100 nm Using V-Shaped External-Cavity for the Pump Laser

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ABSTRACT — **In this research, tunability of a commercial diode laser has extended to about more than ± 11 nm using a V-shaped external-cavity fabricated around the laser. Although under normal condition it can be tuned up to about ± 4 nm just by changing its temperature and injection current. Such modified diode laser has then used in a difference-frequency generation (DFG) experimental setup as pump source in order to continuous tuning of the generated DFG spectrum up to about ± 100 nm from 4.76 µm to 4.85 µm in the mid-infrared region. An $AgGaS_2$ crystal is used as nonlinear medium.**

KEYWORDS: V-shaped External Cavity, Difference-Frequency Generation (DFG) laser, CO spectroscopy.

## I. INTRODUCTION

Difference- frequency generation (DFG) is a very convenient technique for the spectroscopy in mid-infrared (MIR) region of spectrum. Its benefits from room-temperature operation without need to cooling systems, narrow linewidth which is less than a few hundredths of wavenumber and wide tunability. This makes it an efficient source for the spectroscopy in a relatively wide range from ultra-violet (UV) to far-infrared region [1]. The application of a cw DFG radiation as light source has been limited mainly by the lack of suitable laser pump and nonlinear optical crystals [2].

Compared to other light sources, diode lasers are very attractive since operating within different wavelength regions, and of possibility to coarse and fine tuning which can be performed either by changing its operating temperature or injection current, respectively [3]. The main problem faced by a diode laser is the lack of continuity in the wavelength tuning range. This can be improved by incorporating an external-cavity around the laser. In an external-cavity diode-laser (ECDL) structure the required feedback is provided by a tuning element inside the cavity acting as wavelength selector [4].

Therefore, ECDL configurations show promise for narrow bandwidth as well as tunable laser sources that can be arranged into two famous configurations known as Littrow and Littmann devices [4,5]. In those schemes laser wavelength tuning is based on the provided feedback form the surface of an intracavity grating which enables of producing an appreciable radiation within many important molecular transitions [6]. In a typical DFG set up they have been used as one of the input beams to generate wider radiation in the MIR region in order to on-line and in situ trace detection of the most molecular species and combustion-generated pollutants such as carbon monoxide (CO) and nitric oxide (NO) originating from industrial resources and human exhaled breath. However, due to the mode jump behavior of a single mode diode laser, DFG wavelength cannot be continuously tuned over a selected molecular transition band. Apart from Littrow and Littman arrangements, single mode operation and tuning characteristics of a commercial diode laser can be significantly improved by fabricating an external short cavity around a simple diode laser. It is performed using a very thin $(\leq 500\,\mu m)$

uncoated glass plate mounted on a piezo stack and fixed very close ($\leq 200\,\mu m$) to the laser output facet in order to form an external short cavity together with the output facet of laser chip [1, 3].

In the present work we have introduced a V-shaped external-cavity diode-laser as pump source for the generation of a DFG radiation in 4 µm band of spectrum. We found that tuning characteristics of a commercial diode laser is improved by simply turning a blazed grating inside the external cavity resulting relatively wide tunability at the 2nd-order of diffraction. More than 100 nm of DFG tuning has been obtained from the results**.**

## II. Experimental Setup

### A. *Tuning characteristics of the V-shaped external cavity pump diode laser*

In Fig. 1 the characterized spectrum of pump diode laser (HL6738MG) operating at a central wavelength of 690 nm and output power of ~ 30 mW is showed. It is performed by changing its temperature while the injection current is fixed at 97 mA.

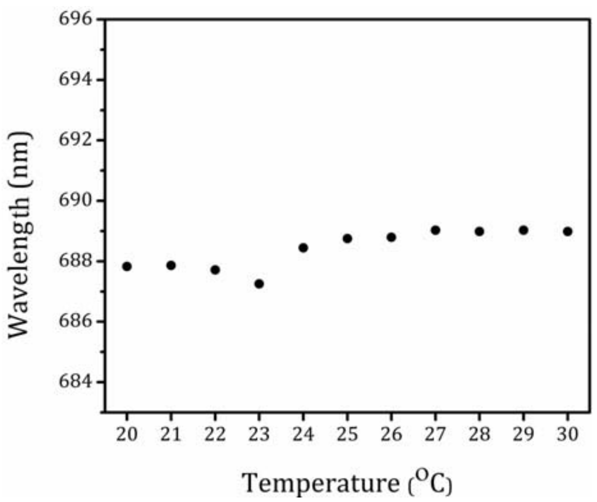


Fig. 1. Spectrum of the pump diode laser output while its operating temperature is changed from $T_d = 20\,°C$ to 30 °C and injection current is set for $i_d = 97\,mA$ .

As illustrated maximum tunability of about ±2 nm is obtained without using external tuning element. In order to extend the tuning feature of the utilized diode we used a V-shaped external cavity around the laser. This resulted to the tuning improvement of about ±11 nm. The schematic of the V-shaped cavity is shown in Fig.2.

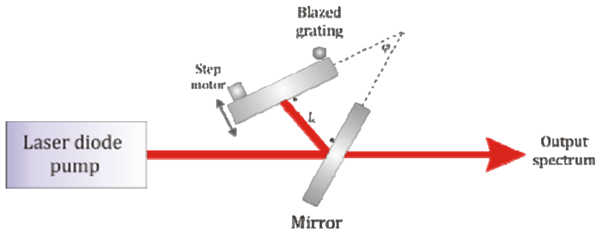


Fig. 2. Schematic of the utilized V-shaped external cavity fabricated around the commercial diode laser (HL6738MG).

As shown, the surface of a ~%40 reflectivity coated mirror is irradiated by the output beam of the laser and then reflected back toward the surface of a blazed grating (Thorlabs, GR25-1208). The grating blazed angle is 28º and it has 1200 groove/mm which provides maximum intensity at the 2nd-order of diffraction. The intracavity grating is mounted on a springy plate connected to a vernier on the rear. Precise rotation of the grating was performed through fine turning of the vernier by using a computerized step motor with a displacement accuracy of ~1.4 µm/degree. Therefore, while the length of V-shaped cavity was changed by ~ ±56 µm, the output wavelength could be tuned over ~ ±1 nm without mode jump.

Physical mechanism of the output wavelength tuning is based on the Littrow condition as can be followed through

$$\Delta\lambda = -\lambda \frac{\Delta L_c}{L_c} \tag{1}$$

where the external-cavity length is changed by $\Delta L_c$. This can be simply performed by turning the blazed angle by

$$\Delta\varphi = -\tan\varphi \frac{\Delta L_c}{L_c} \tag{2}$$

where $\varphi$ and $L_c$ are specified in Fig. 2.

Wavelength tuning of the emerging laser been was then possible by rotating of the grating while the operating current and temperature of the diode were kept fixed on a desired values.

An experimental example of tuning characteristics of the out-coupled laser beam is shown in Fig. 3. Data sampling is performed by a commercial wavemeter (Bristol 821).

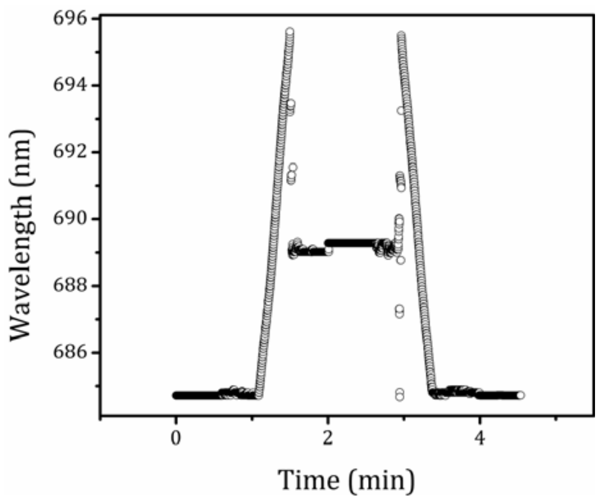


Fig. 3. Measured spectrum of the out-coupled beam while the blazed grating was rotated in a certain range of angles. The diode laser was set at fixed operating temperature and injection current of $T_d = 29\,°C$ and $i_d = 97\,mA$, respectively.

As clearly seen, fine rotating of the blazed grating in opposite directions is resulted to the generation of a symmetrical, very continuous and mode-hope-free spectrum of the diode laser up to ~ ± 11 nm. The left branch in the figure corresponds to the increasing length of the external cavity while the right one is related to the decreasing of the cavity length. However, the extreme mode-hope tuning limit of such commercial diode laser without such V-shaped external cavity was experimentally measured ~ ±3 nm.

Although the length of the V-shaped cavity was changed by ~ ±56 μm wavelength tuning of ~ ±1 nm is obtained. As it can be seen in Fig.4, same behavior was observed for different sets of diode laser operating current and temperature.

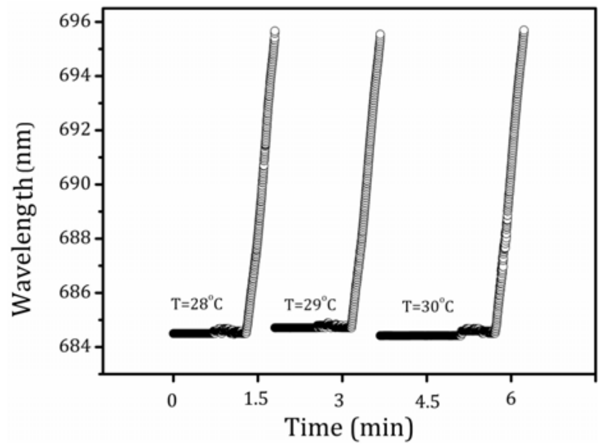


Fig. 4. Output spectrum of the diode pump at three different operating temperatures as $T_d = 28\,°C$, 29 ºC, and 30 ºC. The injection current is fixed at $i_d = 97\,mA$.

The wavelengths stability of the emerging output beam is also measured and the relevant results are shown in Fig. 5.

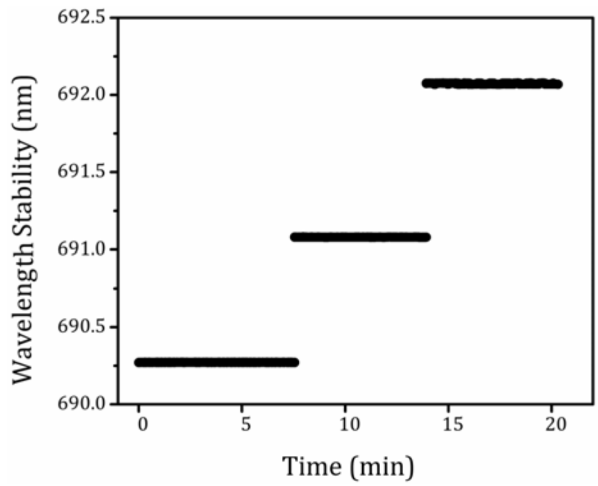


Fig. 5. Spectrum stability of the emerging beam for three different V-shaped cavity lengths during 7 minutes data sampling for each rotating stage. Temperature and injection current of the diode laser were fixed at $T_d = 30\,°C$ and $i_d = 97\,mA$, respectively.

As can be seen the output spectrum of V-shaped cavity indicated good stability which shows promise as a pump source for a DFG experimental set up. Fig. 6 shows whole spectrum of the out-coupled laser beam while its operating temperature is changed within $T_d = 20\,°C$ to 30ºC range whereas the injection current is kept constant.

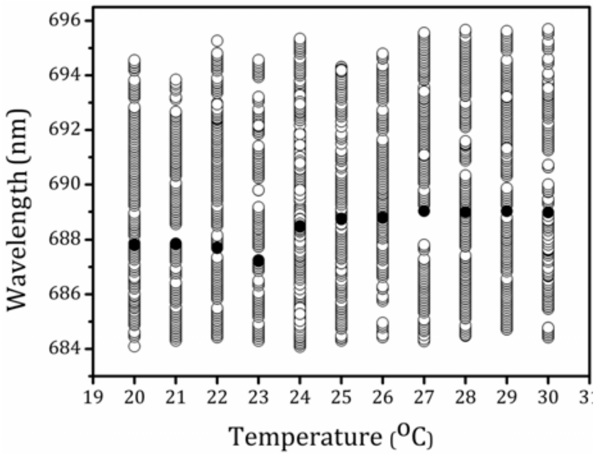


Fig. 6. Output spectrum with (○) and without (●) using fabricated V-shaped external cavity around the pump diode laser. During the measurement temperature of the diode was gradually changed from $T_d = 20°C$ to $T_d = 30°C$ while its operating current was set for $i_d = 97\,mA$.

The most advantage of such V-shaped configuration is that while the blazed grating is rotated to tune the output wavelength of diode laser, the direction of the emerging beam is remained unchanged. Therefore, it can be expected by using V-shaped external cavity diode laser as pump source in a DFG experimental setup maximum overlapping as well as wide tuning of the idler wavelength can be obtained.

## B. *DFG radiation generation in MIR range using V-shaped external cavity for pump laser*

The experimental setup of MIR-DFG radiation utilizing a V-shaped external cavity as pump source is schematically shown in Fig. 7.

The signal source is provided by the output beam of a commercial cw single mode diode laser (DL-8141-035) operating at center wavelength of $\lambda_s = 808\,nm$ with output power of $P = 150\,mW$. An $AgGaS_2$ crystal cut for noncritical 90° phase-matching for type I (e + o → o) interaction is used as nonlinear medium. The output beam of the characterized V-shaped external cavity diode laser is used as pump beam. A polarized beam splitter is applied for mixing output beams of signal and pump sources inside the crystal. Phase-matching condition is performed by using a commercial oven (Thorlabs, TC200) with $\Delta T = \pm 0.1°C$ of accuracy. After passing through the crystal the generated idler beam is the focused on the surface of a N2-cooled MCT detector (MCT, 5-010-LN6N GmbH) using a $CaF_2$ lens. In the front of the detector a 2-mm-thick Germanium filter is the used to block the signal and pump beams. Fig.8 illustrated the accessible phase-matched MIR-DFG wavelengths through tuning the V-shaped external cavity in a desirable range.

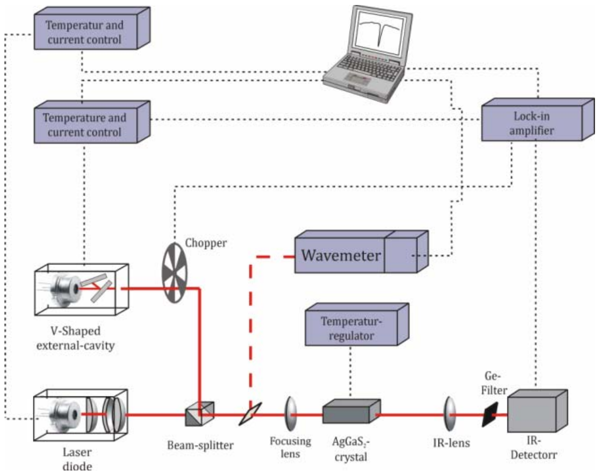


Fig. 7. Schematic illustration of the MIR-DFG experimental setup using a V-shaped external cavity as pump source.

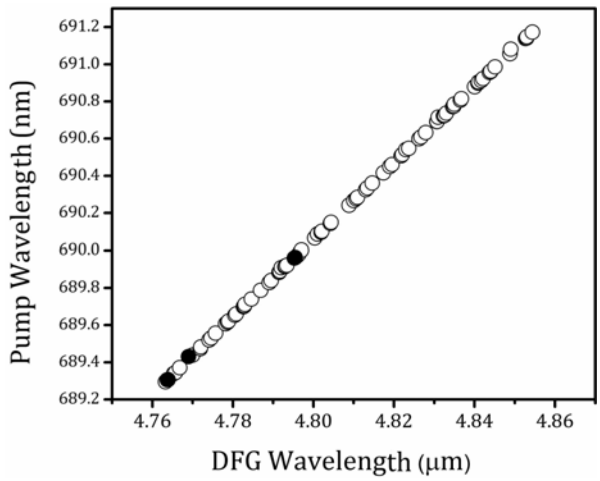


Fig. 8. Measured MIR-DFG tuning bandwidth with (○) and without (●) using the V-shaped external cavity for the pump source.

As can be seen, in addition to a wide tuning of idler wavelength very continuous tunability is obtained from the results. An extension tuning of ~100 nm is also measured for the generated DFG wavelength.

## III. CONCLUSION

We reported the results of the fabrication of a V-shaped external cavity around a commercial diode laser. The characterization of such configuration indicated that tuning feature of the diode can be significantly improved. Maximum tunability of about ±11 nm is obtained from the results. The configured V-shaped cavity is then used as pump source in a MIR-DFG experimental setup. A relatively broad and nearly continuous idler tuning range extended over ~100 nm from 4.76 μm to 4.86 μm is measured. This is very advantageous for the spectroscopy of many molecular species in which long-term stability in both output power and spectrum are required.

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