Optics Laboratory Work: Tunable diode laser based on a MEMS grating

Supervisor :
Salma Farahi
BM 4109
salma.farahi@epfl.ch

1 Objective

The objective of this Optics Laboratory Work is to align and characterize a wavelength tunable external cavity diode laser by means of a MEMS grating. Student should also get familiar with the working principle of a tunable MEMS grating.

★★Safety★★
Working with laser radiation has several risks for the operator, mostly for the skin and eyes. Pay special attention to the following :
— Never look into direct or reflected laser beam
— Do not wear watches, rings or any other object that can reflect laser beam
— Block or turn off the laser beam during alignment or any other optics manipulation
— Keep eyes level higher than laser level i.e. avoid sitting on the chair during experiment
— Optical fibers are made of glass ; be careful during fiber manipulation

2 Introduction

Micro-Electro-Mechanical Systems (MEMS) address the need to make things always smaller, faster, robust. A MEMS component can be represented as a transducer at the micrometer scale, it transforms thus one form of energy into another on this scale. For example, its structure may be mechanically deformable and/or mobile under the influence of pressure, electrostatic, thermal, magnetic or piezoelectric solicitation.

MEMS technology, now relatively mature, was introduced as a solution to the miniaturization of circuits, in the early 80s. Indeed, one aspect that makes them so attractive is that MEMS are manufactured with the same processes as those conventionally used to design integrated circuits based on semiconductors. Mass production and lower manufacturing costs associated are then accessible.

MEMS components are found now in many applications from everyday life. This is the case for example in our cars (accelerometers in airbags), in our television, in video game consoles, or in our mobile phones (accelerometers, gyroscopes, radio frequency filters), etc..

MOEMS : Optical MEMS The term MOEMS (Micro-Optical-Electro-Mechanical Systems) refers to systems that combine optical and electromechanical functions. Compared to bulk optical elements, they benefit from the technologic expertise of microelectronics with a high potential for miniaturization and mass production. They are smaller, lighter, faster and cheaper. Being able to integrate mobile opto-mechanical parts and micro-actuators has opened many new opportunities for optoelectronic systems. A small displacement is sufficient now to achieve an important function in an optical system. Thanks to MOEMS, complex opto-mechanical components can be integrated on a single silicon chip.

MOEMS devices fall into two broad categories : components under the principles of geometrical optics (optical shutter ...) and components based on physical optics (Fabry-Perot micro-optical cavity, micro-mirrors for adaptive optics ...).

They can be used to change the profile, the direction, the intensity, the phase or even the wavefront of a light beam. This beam control is often done through the movement of an object (mirror) but can also, for example, be achieved by imposing a mechanical stress.

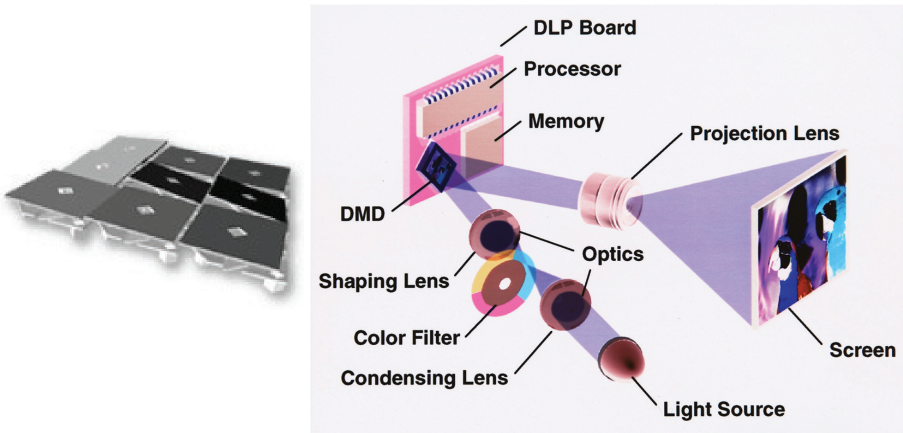

FIGURE 1 – A DMD micro-mirror from Texas Instruments and its integration in a DLP® system (www.dlp.com).

Some MOEMS applications The introduction of an optical component in the field of MEMS has opened significant fields of application for these devices, whether in the fields of telecommunications, astronomy, automotive, avionics or biological and medical engineering. These components have now well established micro-systems attributes that make them so attractive for industrial and commercial development (low-cost mass production).

— The telecommunications field was the first to integrate MOEMS devices. The use of MOEMS has become the most attractive for optical switching as it revolutionizes optical communications. Indeed, at a time when one wishes to develop high speed "all optical" telecommunication networks, MOEMS allow routing or addressing optical signals without using an optical/electrical interface.

— One of the biggest MOEMS success is the DLP® system (Digital Light Processor) developed by Texas Instruments from the 1990s for image projection. This system involves a micro-mirrors matrix (DMD, igital Mirror Device) placed on a CMOS chip, a light source, a chromatic element and a projection lens (Figure 1) . The chip can hold up to 2 million DMD (having a size of about 10 μm x 10 μm) and is not larger than a stamp. Currently, these chips are used for projecting images (video projection), in televisions (flat screens with DLP® technology), and very recently, in mobile phones integrated pico-projectors.

— MEMS micromirrors are also increasingly present in the field of optical imaging endoscopy, where their role is to guide an optical beam along one or two axes to scan the area to be imaged .

— Astronomical imaging has also demonstrated the potential of micro-electromechanical components. The main application of MOEMS in this area is related to adaptive optics often using deformable mirrors to correct atmospheric aberrations. MOEMS devices allow to increase the density of actuators per unit area, thus increasing the accuracy of the system.

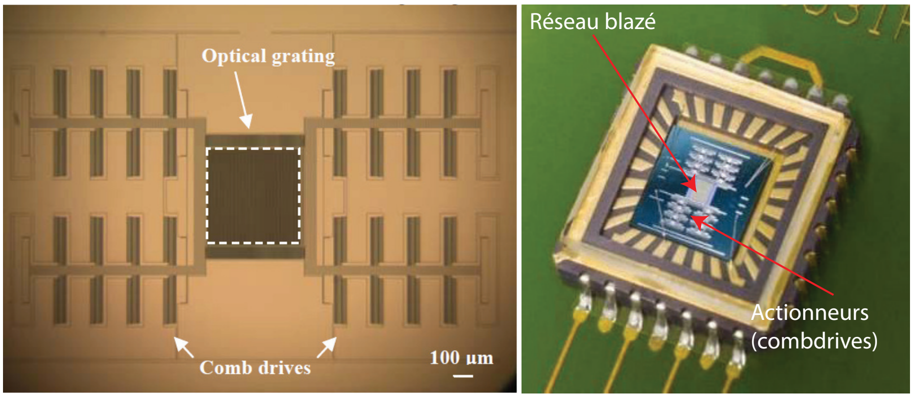

FIGURE 2 – MEMS grating pictures.

3 Characterization of the blazed grating with variable pitch

3.1 MEMS grating description

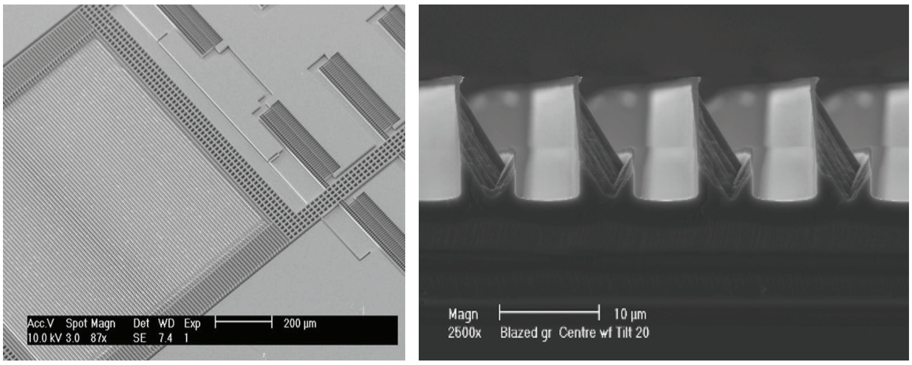

FIGURE 3 – Scanning electron microscope images of the MEMS grating

Figures 2 and 3 show different images of the MEMS system that you will use. It is a micro-device consisting of an optical grating and a set of electrostatic actuators (comb drives). The complete matrix measures 6 mm x 3 mm with a grating of 1 mm x 1 mm. The grating is formed by a set of micro-mirrors attached by springs. The pitch is equal to 12 μm with a duty cycle of 50% and the blaze angle is $\theta_B = 54.75°$ (see figure 4). **The application of a voltage to the actuators allow the control of the grating period**.

Figure 4 shows a schematic representation of the grating in a Littrow configuration. The plane of the array is inclined with respect to the optical axis such that the facets of the grating are almost perpendicular to the optical axis.

3.2 Theoretical study of a blazed grating

A blazed grating is a type of reflection grating with a stepped profile. The N reflective steps have a width a and a height h (Figure 5). We assume that the steps have in the x direction (perpendicular to the figure), a very large length compared to a. This grating is illuminated by a monochromatic source in the form of an infinite slit in the x direction. Diffraction is then reduced to a two dimensional problem (in the figure plane). The light source S is at infinity in a direction making an angle i with the micro-mirros normal. We will then look for the diffraction pattern intensity at infinity as a function of the reflected rays angle r.

Question 1 :
Before any calculation, what can one say of the diffraction pattern of such a system ?

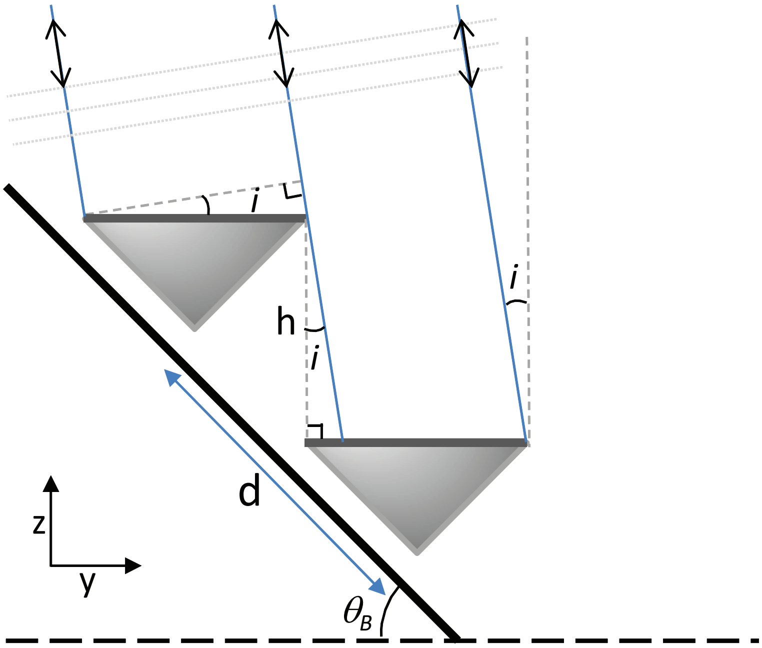

FIGURE 4 – Blazed grating (2 mirrors) in a Littrow configuration

To find the expression of the diffracted intensity we should first calculate the phase shift introduced by the whole grating. The path difference between a beam reflected at the center of the first mirror (at O_0) and a beam reflected at any point M located on the n^{th} mirror can be expressed as a function of a', the algebraic distance O_nM (See Figure 5).

If we note S the source and P a point at infinity in the r direction, we can express δ the path difference as :

$$\begin{aligned}\delta &= [SMP] - [SO_0P] = ([SM] - [SO_0]) + ([MP] - [O_0P]) \\ &= KM - O_0H \\ &= \overrightarrow{O_0M} \cdot \overrightarrow{u_i} - \overrightarrow{O_0M} \cdot \overrightarrow{u_r} \\ &= n[a(sin\ i - sin\ r) + h(cos\ i + cos\ r)] + a'(sin\ i - sin\ r) \qquad (1)\end{aligned}$$

To simplify this expression we will call :

$$\begin{aligned}\alpha &= a(sin\ i - sin\ r) + h(cos\ i + cos\ r) \\ \beta &= sin\ i - sin\ r\end{aligned}$$

The phase shift φ between the two beams is then :

$$\varphi = 2\pi\frac{\delta}{\lambda} = 2\pi\frac{n\alpha + a'\beta}{\lambda} \qquad (2)$$

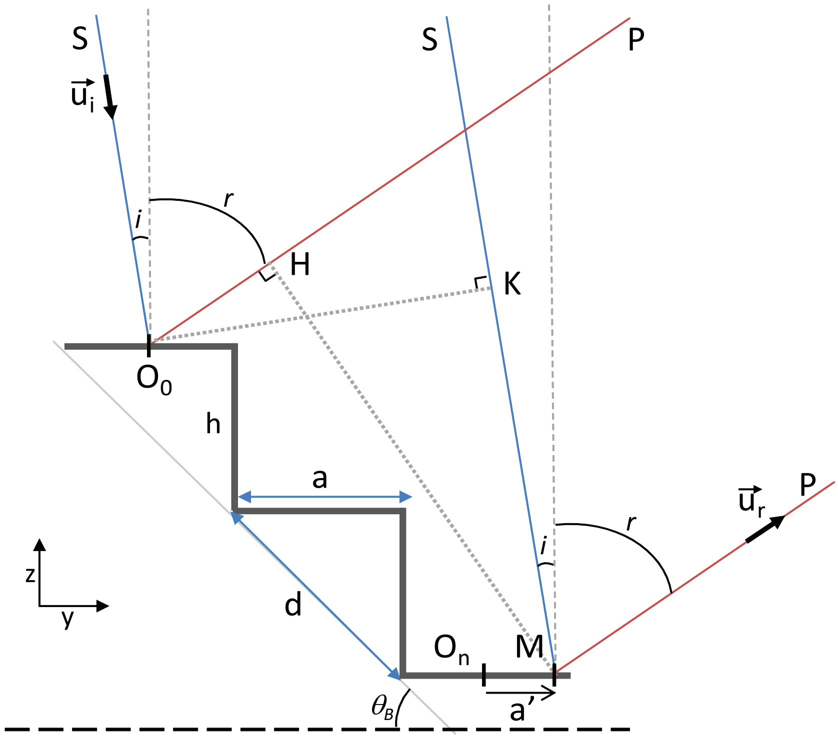

FIGURE 5 – Grating with a stepped profile

Using the **Huygens–Fresnel principle** one can express thus the diffracted field in the r direction. We note E_0 the amplitude of the field diffracted by a thin slice of the grating. We obtain the entire diffracted field by integrating the phase facto $e^{j\varphi}$ over the entire system :

$$\begin{aligned} E &= \int_{system} E_0 e^{j\varphi} da' = E_0 \sum_{n=0}^{N-1} \int_{step\ n} e^{j\varphi} da' = E_0 \sum_{n=0}^{N-1} \int_{-a/2}^{a/2} e^{j\frac{2\pi}{\lambda}\frac{n\alpha + a'\beta}{\lambda}} da' \\ &= E_0 \sum_{n=0}^{N-1} [(e^{j\frac{2\pi}{\lambda}\alpha})^n \int_{-a/2}^{a/2} e^{j\frac{2\pi}{\lambda}\beta a'} da'] \\ &= E_0 \ \left(\int_{-a/2}^{a/2} e^{j\frac{2\pi}{\lambda}\beta a'} da'\right) \ \left(\sum_{n=0}^{N-1} (e^{j\frac{2\pi}{\lambda}\alpha})^n\right) \\ &= E_0 \ e^{j\frac{2\pi}{\lambda}\beta a} \ a \ sinc(\frac{\pi\beta a}{\lambda}) \ \frac{sin(\frac{\pi N\alpha}{\lambda})}{sin(\frac{\pi\alpha}{\lambda})} \ e^{j\pi(N-1)\alpha/\lambda} \end{aligned} \tag{3}$$

Starting from the expression in equation 3, we can find the expression of the diffracted intensity in the r direction.

$$I = \frac{I_0}{N^2} \, sinc\Big(\frac{\pi\beta a}{\lambda}\Big)^2 \, \Big(\frac{sin(\frac{\pi N\alpha}{\lambda})}{sin(\frac{\pi\alpha}{\lambda})}\Big)^2 \quad \text{where} \quad I_0 = (aE_0N)^2 \tag{4}$$

I_0 is then the intensity that would have been produced by a reflective surface of same size as the grating.

Question 2 :
Comment the expression of the diffracted intensity given in equation 4.

Question 3 :
Where is the maximum of the diffraction pattern ? Specify the values of the principal maxima r_p of the diffraction pattern as a function of λ, a, i and an non-zero integer p. We are in the small angles approximation.

Question 4 :
Show that one can choose the grating parameters so that an order p_0 of the grating coincides with the direction of the maximum diffraction by a single mirror. What are the advantage over a conventional diffraction grating ?

We consider now that we are in a Littrow (figure 4) configuration with a normal incidence angle ($i = 0$).

Question 5 :
Show that the order p_0 can be expressed as $p_0 = 2dsin\theta_b/\lambda$, where d is the grating period and θ_b the blaze angle. Give a simplified expression of the intensity.

The width $\delta\lambda$ of each peak of the diffraction pattern is given by the distance between the first minimum on each side. The free spectral range $\Delta\lambda_{FSR}$ is the difference in wavelength between two adjacent diffraction orders. These two variables give the the features of the grating and can be expressed as :

$$\delta\lambda = \frac{\lambda^2}{Nh} \quad \text{et} \quad \delta\lambda_{FSR} = \frac{\lambda}{p_0} \tag{5}$$

Question 6 :
Calculate p_0, $\delta\lambda$ et $\delta\lambda_{ISL}$ for the MEMS grating described above at $\lambda = 660\ nm$.

3.3 Experimental characterization of the MEMS grating

The aim of this experimental part is to illustrate the previous theoretical results.

Question 7 :
Build the experimental setup presented in figure 6.

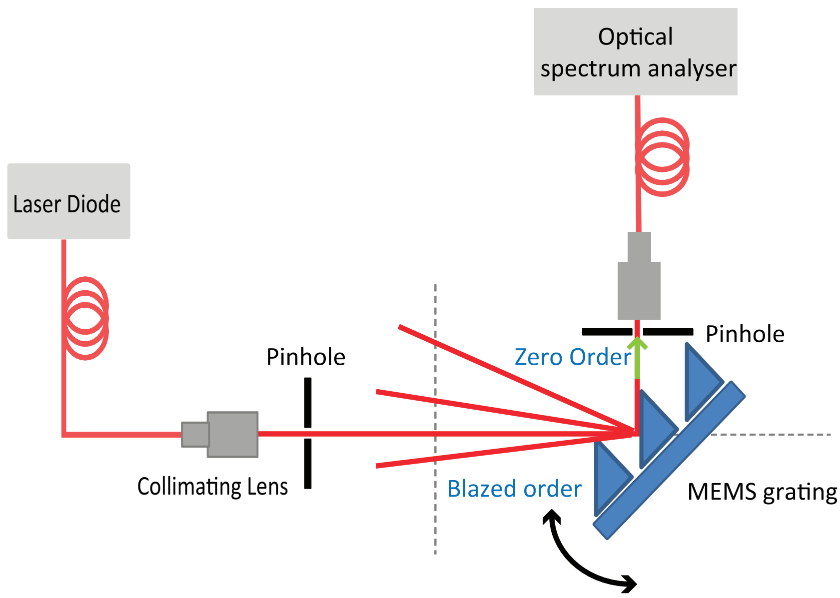

FIGURE 6 – Experimental setup for MEMS blazed grating characterization

A fibre laser diode emitting at $\lambda = 660\ nm$ is used for the grating charachterization. The grating must be close to a Littrow configuration. Align the laser on the grating and optimize the intensity of the diffracted orders by translating and rotating the grating.

Question 8 :
Find the blazed order. Is it where it is expected ?

Inject light coming from a diffracted beam into the Optical Spectrum Analyser (fibre). Use a power-meter to optimize the intensity at the fibre output.

Question 9 :
Measure the width of a diffraction peak. Is this consistent with the theoretical prediction ?

Apply a voltage to the comb drives of the grating (**Voltage limit : 60V !**)

Question 10 :
What happens when you apply a voltage to the grating ?

4 Building of an external cavity tunable laser (ECTL)

One of the most important application of MEMS blazed gratings is the implementation as a wavelength selective element in an external cavity tunable lasers (ECTL). The majority of MEMS external cavity tunable lasers use rotatable gratings to perform the wavelength selection. Rotation of the blazed surfaces will thus lead to loses in the optical efficiency. The benefit of the studied tunable MEMS grating is that it can remain positioned at fixed angle (light reflected from the grating still coupled to the laser and the efficiency is maintained), while tuning is achieved by modifying the period of the grating through electromechanical stretching.

We will use a laser diode emitting at $\lambda = 785\ nm$ coupled with the grating to realize a tunable laser.

The blazed grating will act as a reflective spectral filter (in Littrow configuration) where the diffracted light (blazed order) is directed back to the laser diode. The highest efficiency is achieved when the blazed surfaces are perpendicular to the incident light signal.

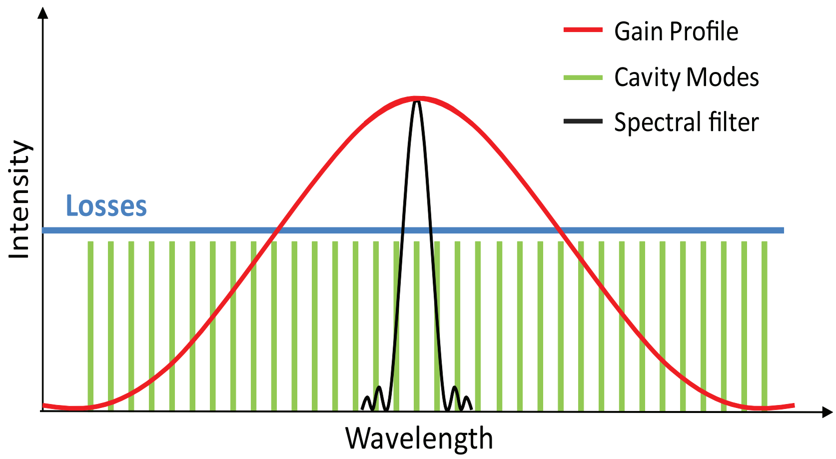

FIGURE 7 – The gain profile of the laser, the cavity modes and the spectral filter function of the external cavity grating. The three spectra combine allowing a single mode to lase. The additional peaks under the gain profile and the spectral filter function suffer too much loss to lase.

Mode selection The spectrum of the emitted signal from the ECTL is a combination of the laser cavity modes, the spectral filter and the gain profile of the lasing medium.

The cavity modes are the longitudinal modes which propagate based on the optical length of the cavity. therefore the cavity modes are a series of closely spaced narrow peaks (see figure 7).

A spectral filter, if narrow enough, can increase the losses in all but one mode to establish a single mode laser.

Question 11 :

Realize the experimental setup described in figure 8. The blazed order is sent back to the lase diode. The zero order is thus the ECTL output. One can use a beam sampler to pick up a part of the light coming from the laser diode to optimize the feedback with

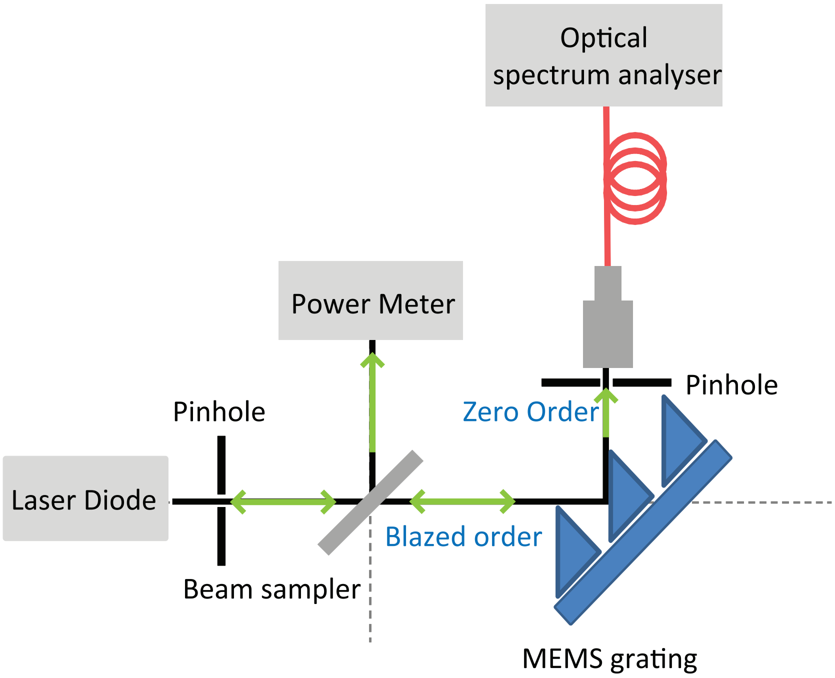

FIGURE 8 – Experimental setup for external cavity laser building

a power meter.

Question 12 :
Measure the laser output wavelength (thanks to the Optical Spectrum Analyser) while changing the applied voltage to the MEMS grating. The zero order beam should be first coupled to the OSA fibre.

References : -"Fundamentals of photonics", B.E.A Saleh and M.C. Teich, Chapter 15.