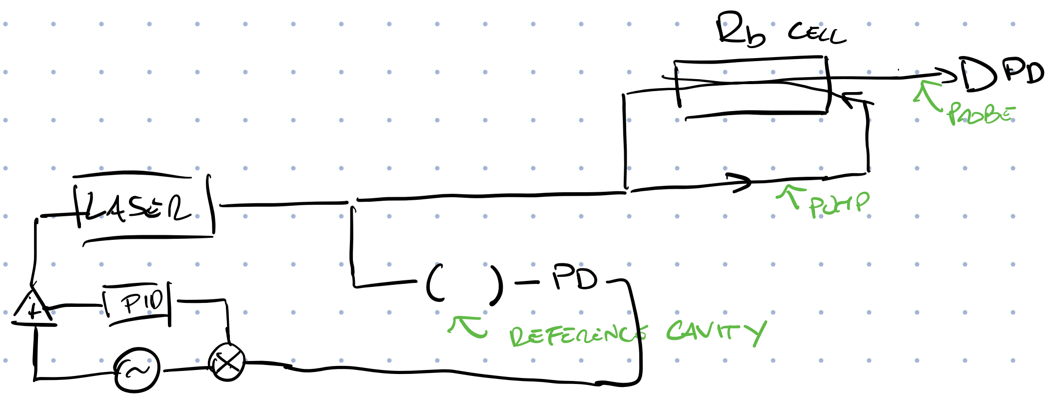
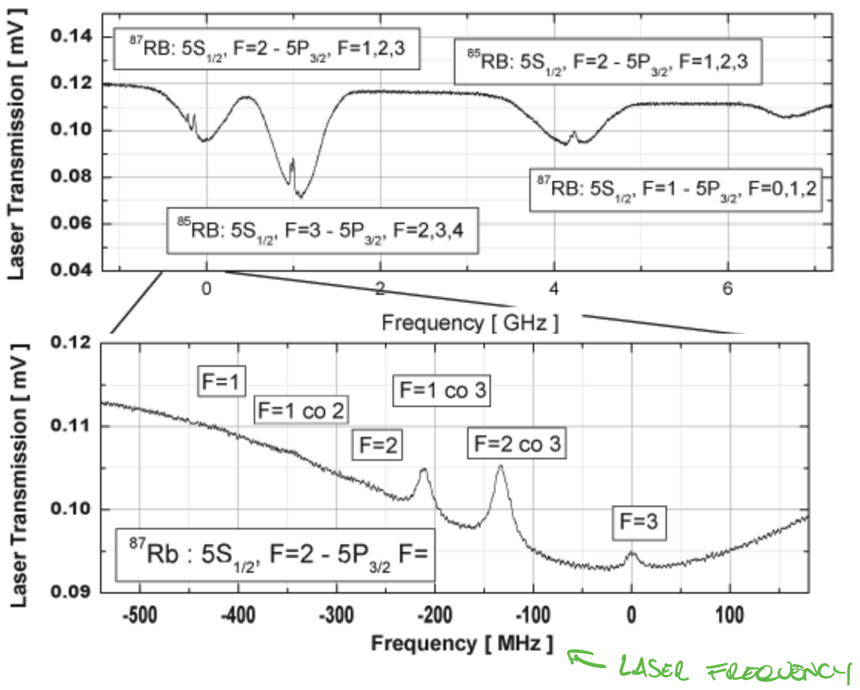
## Experimental setup



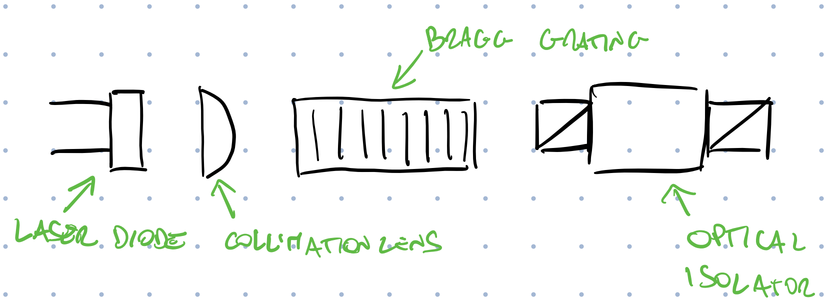

The goal of the experiment is to observe doppler-free absorption spectroscopy of Rb in a glass cell




To be able to reach this final goal we will need to scan the laser frequency over various ranges. The laser frequency can be controlled either with the temperature (very slow) or with the current.The other important thing is that the laser remains single mode (meaning that it has one single emission frequency that does not jump around but follows the desired frequency sweep)

## The laser

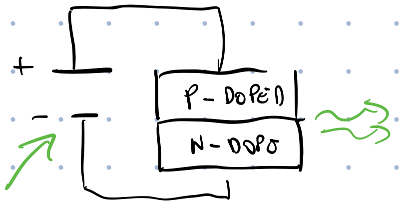
The laser we use is a Volume Bragg Grating (VBG) laser diode from IPS photonics. It is a type of laser diode that uses a Bragg grating for wavelength stabilization

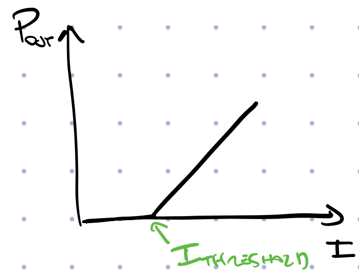



The laser is composed of 4 main components. A semiconductor laser diode, a collimation lens, the Bragg grating and an optical isolator. Let's look at the role of each component:

Laser diode: The most common semiconductor diode types are junction diodes, that are built with two semiconductor materials on top of each other. One layer is p-doped (vacancies) and the other is n-doped (electrons). If the two materials are different the diode is an heterojunction diode.

MOST COMMON ONES!

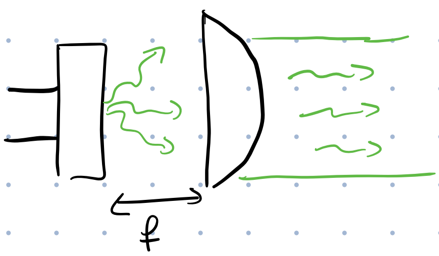



CURRENT DRIVER TO EXCITE ELECTRONS IN THE CONDUCTION BAND AND START THE LASING PROCESS

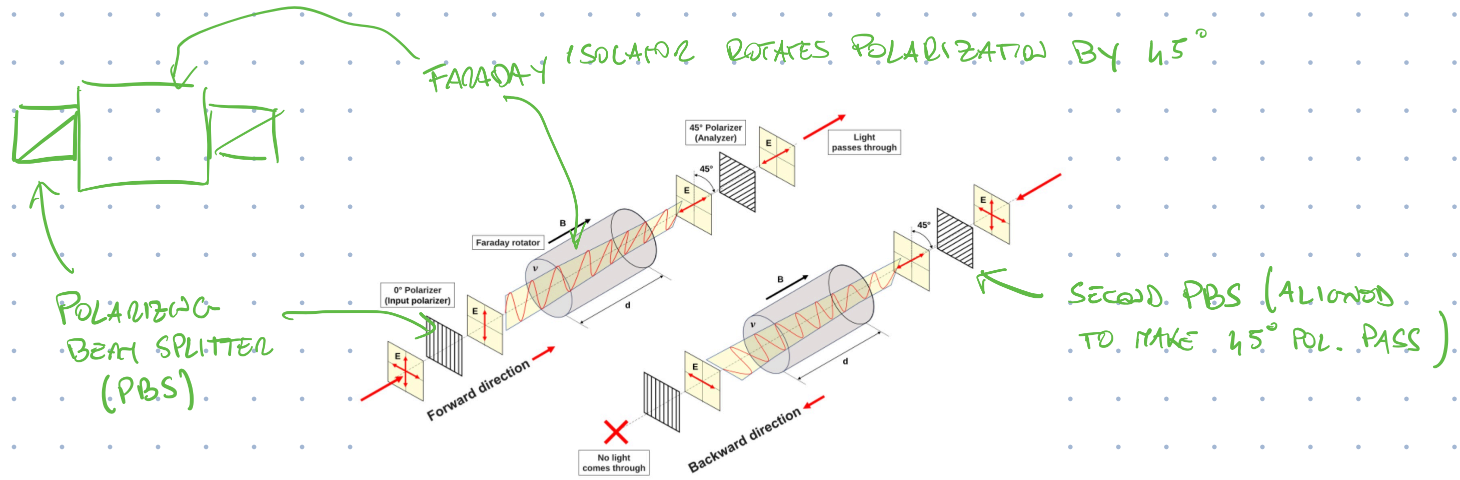
Electrons in the conduction band radiatively fall emitting photons at different wavelengths. The side surfaces of the diode are flat and reflecting, thus creating a cavity. Changing the diode temperature we change the energy gap between the conduction band and the valence band. A lower temperature enlarges the gap thus reducing the emitted wavelength. This is a good tuning knob to roughly center the diode emission in the desired range but it is not usable if we need to scan the wavelength fast The other tuning knob is the current. The current changes the number of electrons available, thus changing the number of photons. So higher currents lead to higher laser intensities. At the same time, tuning the current can also influence the laser emission wavelength. At higher current, the presence of more electrons can lead to electron-vacancy recombination at higher energies, thus leading to shorter emission wavelengths.

Photon emission from the facets of the diode can be imagined as a point source. To collimate the beam we then use an aspheric lens position one f away from the diode face




The other important element in this laser is the volume Bragg grating. The laser emission is not at a single wavelength (there are a lot of possible decays from multiple bands). The periodic refractive index modulation of the VBG selectively reflects back only one wavelength (the desired one) towards the laser diode while allowing all other wavelengths to pass through. Therefore, the VBG seeds the diode with a precise wavelength forcing the diode to lase only at this particular wavelength.

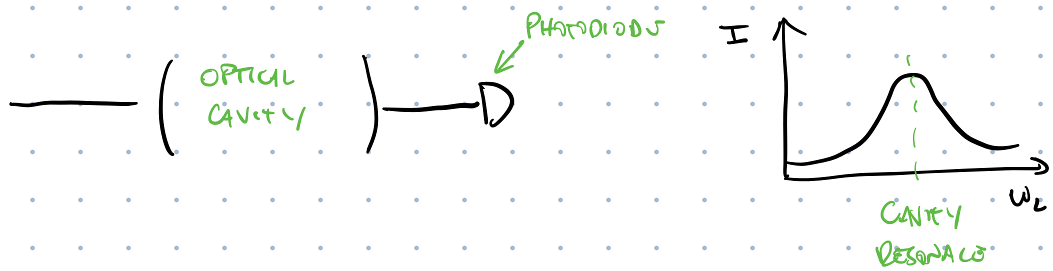
The final element in the picture is the optical isolator that is used to prevent back reflections to enter the laser.



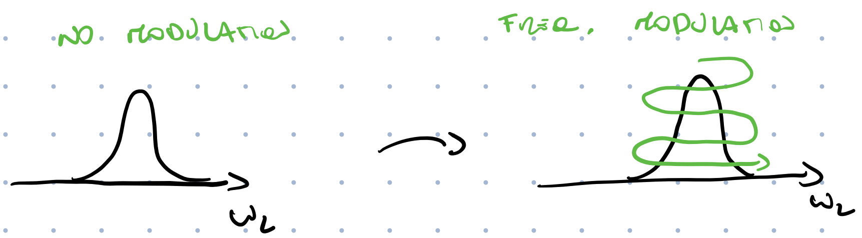

## Locking to the reference cavity

All we have seen so far is the laser and what is contained inside of it and we have seen some of the tuning knobs we have. Our goal is to scan its frequency to measure the absorption resonance of Rb. One way of doing it would be to scan the laser frequency with the current. However, instead of simply doing this we are going to first lock the laser to a reference cavity and then scan the cavity resonance to make the laser follow the frequency. In this way, if the laser remains locked to the cavity, we can be sure that it remains single mode over the entire scan (emitting at a single frequency)

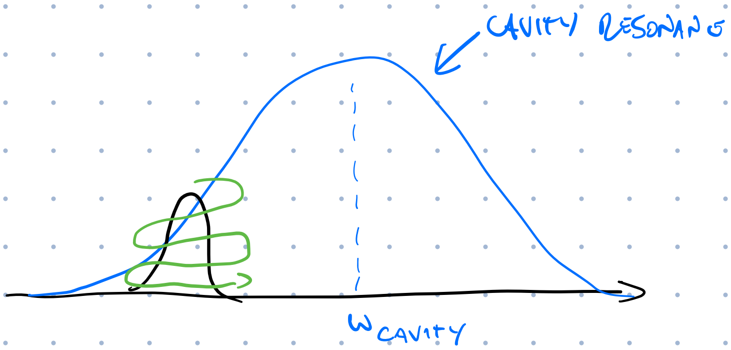
To achieve this goal we are going to use the lock-in. With the ruby experiments we did AM spectroscopy where we modulated the intensity with the chopper. In this case we are going to do FM modulation, modulating the laser frequency with the current.

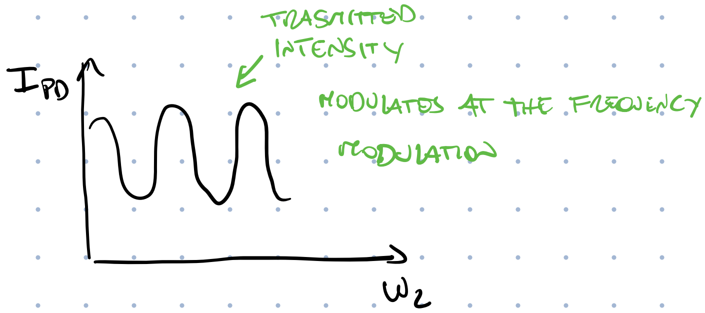



The core of FM spectroscopy is the modulation of the laser frequency and its effect on the intensity of the light transmitted by the cavity. Consider the situation where the modulation frequency is low (compared to the cavity linewidth) and its amplitude small. In this case the laser frequency can be thought as a periodically increasing and decreasing by small amounts

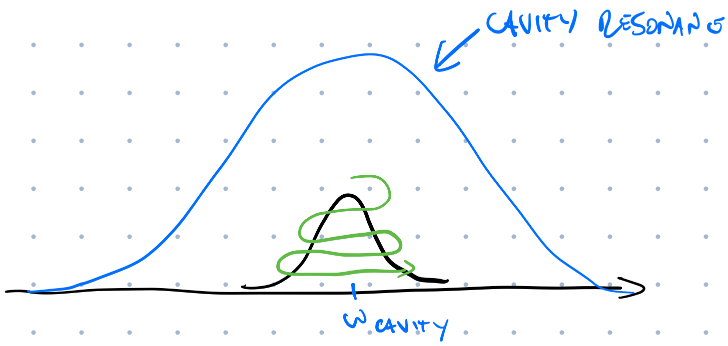


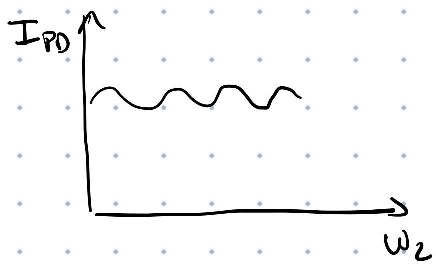

When the laser frequency is close to the cavity resonance, the intensity of the transmitted light is also modulated



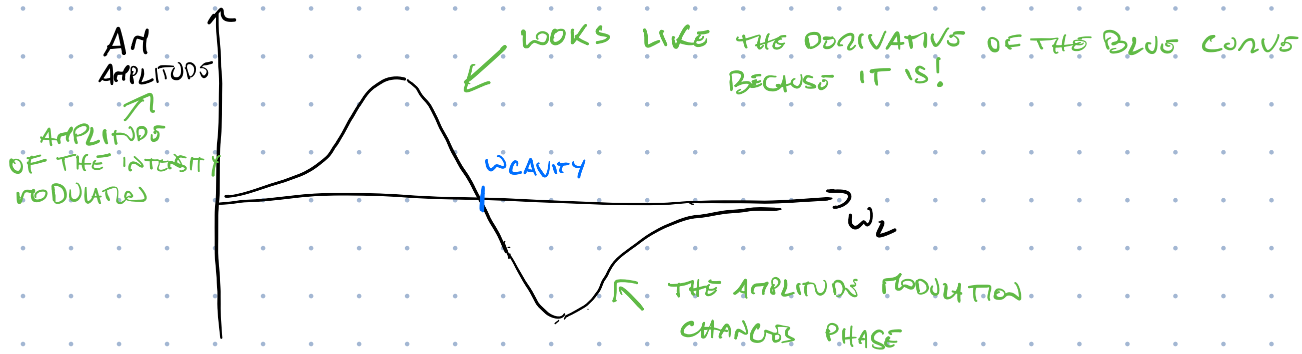




Instead when we are close to the center frequency of the cavity the intensity modulation is not much (it is a maximum, so small changes in frequency do not cause a change of intensity)




O course, the intensity modulation gets larger when we are on the other side of the cavity. We can thus say that we used the cavity resonance to convert frequency modulation into amplitude modulation




CONSIDER FREQUENCY MODULATION AT FREQUENCY $\Omega$ AND AMPLITUDE $A$

$\Rightarrow$ THE TRASMITTED INTENSITY IS $I_T = I(\omega_L + A\sin\Omega t)$

TAYLOR EXPAND

$$I_T = I(\omega_L) + A\sin\Omega t\,\frac{dI_T}{d\omega_L} + A^2\frac{\sin^2\Omega t}{2!}\frac{d^2I}{d\omega_L^2} + \dots$$

$$= \left[I(\omega_L) + \frac{A^2}{4}\frac{d^2I}{d\omega_L^2} + \dots\right] + \sin(\Omega t)\left[A\frac{dI}{d\omega_L} + \frac{A^3}{8}\sin^2\Omega t\,\frac{d^3I}{d\omega_L^3} + \dots\right]$$

$$+ \cos(2\Omega t)\left[-\frac{A^2}{4}\frac{d^2I}{dt} + \dots\right] +$$

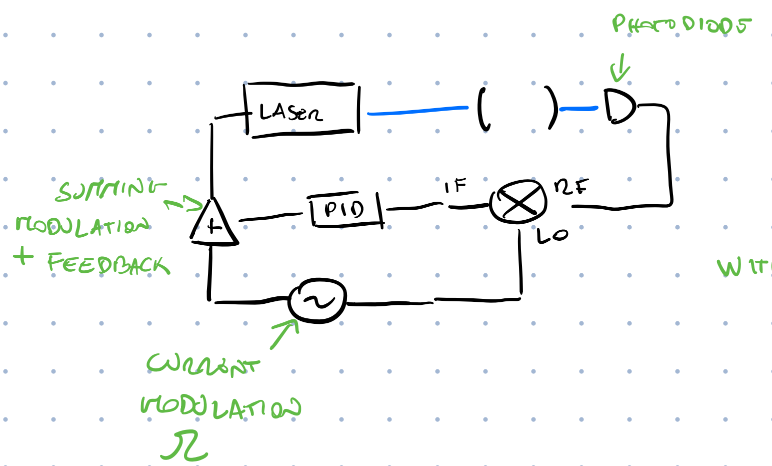
$= \text{DC TERM} + \sin \Omega t \, [\dots] + \cos 2\Omega t \, [\dots] + 3\Omega \text{ TERM} + \dots$

With a lock-in amplifier we can extract the term oscillating at $\Omega$. SINCE $A$ IS SMALL

WE CAN IGNORE $A^3 \dots \Rightarrow$ ONLY FIRST DERIVATIVE

$\Rightarrow$ WE EXTRACT THE DERIVATIVE OF $I_T$ ! (PICTURE ABOVE)

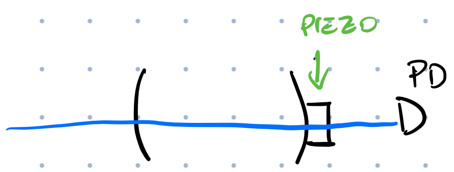
We can then use this asymmetric signal to feedback on the laser to lock it to the cavity resonance. Every time the signal is positive, we need to increase the frequency of the laser, while when it is negative we reduce it. The feedback is done on the laser current

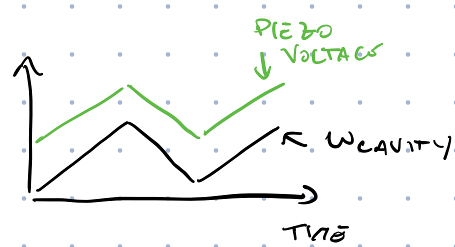



WITH THE MIXER ⊗ WE DEMODULATE THE SIGNAL PICKING ONLY THE COMPONENT OSCILLATING A $\Omega$

WITH PID WE FEED BACK ON THE LASER.

The cavity we use has a tunable length. One of the mirrors is glued on a piezo, that expands or contracts depending on the applied voltage. Changing the piezo voltage, we modify the cavity length, thus the cavity frequency. Therefore, scanning the piezo, allows to scan the laser frequency (if the laser is locked)




## Experimental steps:

1. Characterize the laser diode (threshold current, emission wavelength)
2. Couple the diode to the cavity
3. Lock the diode to the cavity
4. Setup the Doppler free absorption spectroscopy
5. Scan the laser frequency and look at Rb absorption without the pump
6. Scan the laser frequency and look at Rb absorption with the pump