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Saturated Absorption Spectroscopy of Rubidium for Atomic Clock and Magnetometer

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Abstract - *Saturated absorption spectroscopy (SAS) or Doppler-free spectroscopy is a set-up that enables the precise determination of the transition frequency of an atom between its ground state and an optically excited state. The accuracy to which these frequencies can be determined is, ideally, limited only by the width of the excited state, which is the inverse of the lifetime of this state. However, the samples of atomic gas that are used for that purpose are generally at room temperature, where the measured frequency distribution is highly broadened due to the Doppler effect. Saturated absorption spectroscopy allows precise spectroscopy of the atomic levels without having to cool the sample down to temperatures at which the Doppler broadening is no longer relevant. It is also used to lock the frequency of a laser to the precise wavelength of an atomic transmission in atomic physics experiments.*

Key Words: Atomic clock, Atomic magnetometer, SAS, LASER, Rubidium.

1. INTRODUCTION

In this experiment we will use a VCSEL (Vertical Cavity Surface Emitting Laser) diode laser to carry out laser spectroscopy of rubidium atoms. We will use the technique of saturated absorption spectroscopy to study the lines with resolution beyond the Doppler limit. This will enable us to measure the hyperfine splittings of one of the excited states of rubidium. We will use a balanced photodetector to perform background suppression and noise cancellation in the photo-detection process. Lock-in amplifier can be used for locking the LASER at particular wavelength using servo loop.

1.1 SATURATED ABSORPTION SPECTROSCOPY

In SAS a Doppler-free signal is generated using a strong pump and a weak probe travelling in the counter propagation geometry and intersecting in a vapor cell. The pump beam saturates/optically pumps an atomic transition and makes the medium relatively transparent fir the probe beams, the latter sees the relative transparency only at the centre of the atomic transition frequency where both the pump and probe beam interact with the same velocity group of atoms. The enhanced transmission of the probe beam at the line center thus constitutes the SAS signal. At any other frequency they interact with different velocity group of atoms, thereby making the transmission of the probe independent of the presence of the pump beam.

2. EXPERIMENTAL SET-UP

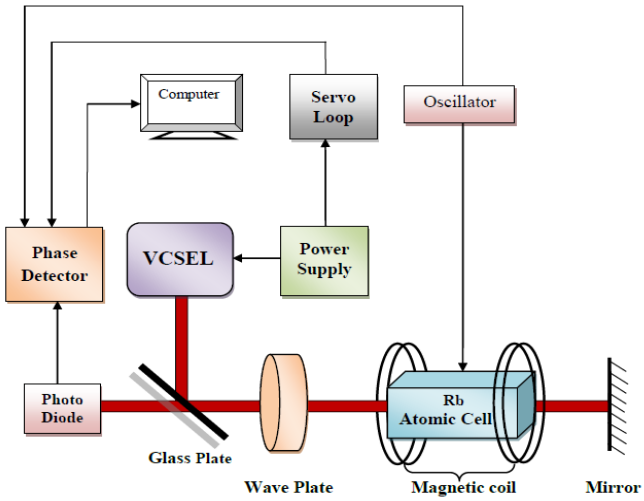

Fig -1: Experimental set-up

VCSEL (Vertical Cavity Surface Emitting Laser) diode at 795 nm with a line-width of ~100 MHz is used as a source for producing Laser light. The power of the laser beam is ~230 µWand it has a knife edge width of ~4.5 mm at the interaction regime. This laser light is reflected in one direction as shown figure 3.1 where the quarter wave plate is used to control the diode laser beam polarization and intensity. Rubidium atomic cell with magnetic copper winding is placed after wave plate, the copper winding around the cell provides magnetic field to atoms or cell. When Laser goes through the cell the atoms get excited and it can be seen as fluorescence with the help of camera on computer. Mirror is used reflect back the incoming Laser light and this Laser light is captured by the Photodiode. Photodiode shows the absorption spectrum of atoms with the help of phase detector.

The absorption spectrum can be seen on the computer. Servo loop adjusts the gain of laser diode and stabilizes it;

Servo loop also locks the laser at particular wavelength. A thermo-electric cooler, a transistor based sensor, and a servo loop is used to stabilize the laser diode at 24°C. The diode laser is frequency modulated at ~2.9 kHz with an amplitude of modulation corresponding to ~1.5 GHz for FM spectroscopy. The laser beam is propagates along the x-axis and the semi-major axis of the laser polarization is along y-axis. Rubidium (Rb) atoms in natural isotopic composition at 50 torr Neon buffer gas is filled in the atomic cell (CELL1, length = diameter = 25 mm). It is heated up to ~52°C, where line width of atomic absorption is measured to be ≥2 GHz. The heater assembly consists of a pair of resistive wire carrying DC current in opposite direction.

2.1 Rubidium Atom (Rb)

Rubidium is a chemical element with symbol Rb and atomic number 37. Rubidium is a soft, silvery-white metallic element of the alkali metal group, with an atomic mass of 85.4678. Elemental rubidium is highly reactive, with properties similar to those of other alkali metals, such as very rapid oxidation in air. Natural rubidium is a mix of two isotopes: 85Rb, the only stable one, constitutes 72% of it. The remaining 28% is the slightly radioactive87Rb with a half-life of 49 billion years more than three times longer than the estimated universe. Rubidium was discovered in 1861 by Robert Bunsen and Gustav Kirchhoff, in Heidelberg, Germany, in the mineral lepidolite through the use of a spectroscope. Because of the bright red lines in its emission spectrum, they chose a name derived from the Latin word rubidus, meaning "deep red". Rubidium is present as a minor component in lepidolite. Kirchhoff and Bunsen processed 150 kg of a lepidolite containing only 0.24% rubidium oxide (Rb2O). Both potassium and rubidium form insoluble salts with chloroplatinic acid, but these salts show a slight difference in solubility in hot water. Therefore, the less-soluble rubidium hexachloroplatinate (Rb2PtCl6) could be obtained by fractional crystallization. After reduction of the hexachloroplatinate with hydrogen, this process yielded 0.51 grams of rubidium chloride for further studies. The first large scale isolation of caesium and rubidium compounds, performed from 44,000 liters of mineral water by Bunsen and Kirchhoff, yielded, besides 7.3 grams of caesium chloride, also 9.2 grams of rubidium chloride. Rubidium was the second element, shortly after caesium, to be discovered spectroscopically, only one year after the invention of the spectroscope by Bunsen and Kirchhoff.

3. CONCLUSIONS AND OBSERVATIONS

Figure 3.1 shows the Doppler-broadened spectrum lines when the overlap beam is blocked. This is equivalent to ordinary laser absorption spectroscopy, where a single laser beam passes through a vapor cell to a photodiode. As the laser passes through the cell, the stimulated emission and absorption processes change the intensity of the laser measured by the photodetector and Doppler-shifts of the rubidium atoms cause the signal to be Doppler-broadened. The two signals of larger amplitude are of 85Rb; whereas the outer two dips correspond to absorption in 87Rb. The reason that the signal from 85Rb is considerably larger than 87Rb is because it is roughly three times more abundant.

The output of Saturated Absorption Spectroscopy (SAS) is shown in below figure 4.1. The output is restricted to 0v to 2v, the red signal shows the output of SAS signal as well as the black signal shows the output of lock-in-amplifier. Following are the snapshots of the output taken from computer.

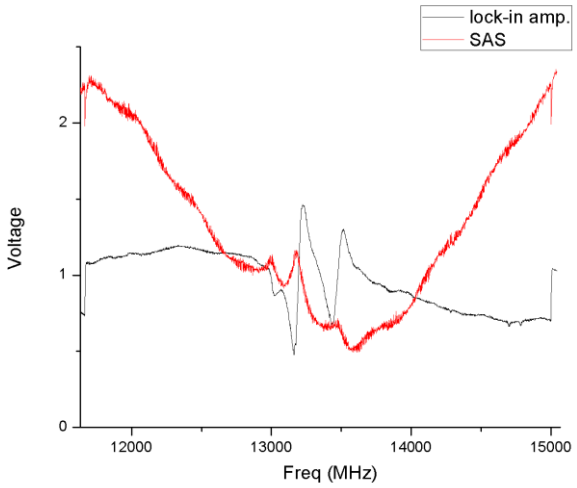

Fig 3.1 Output of SAS and lock in amplifier

The peaks between 13000 to 14000 MHz shows the SAS and lock-in amplifier signals observed of the rubidium atom. After observing SAS and lock-in amplifier, we have done the next objective that is laser locking that is locking the Laser at particular wavelength.

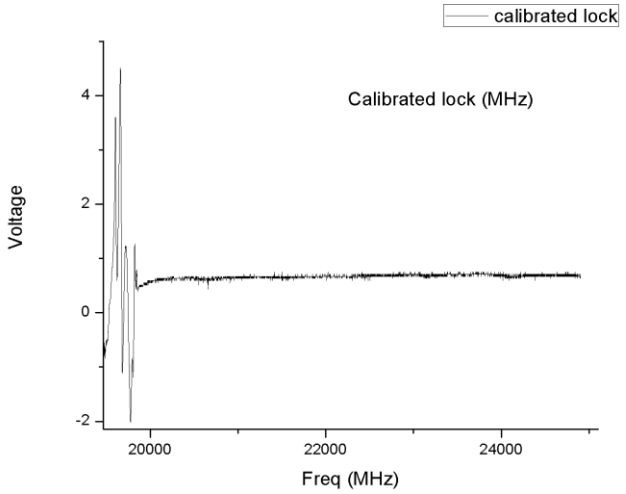

Fig 3.2 Output after Laser is locked

Figure 3.2 shows the output when laser is locked at particular wavelength. As shown in figure the laser is giving

constant frequency (after 20000 MHz) at particular wavelength after Laser is locked. All the readings have been taken in the Origin software and then we have taken the snapshots or images of the result.

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