

Precise laser stabilization is a fundamental aspect of modern metrology, directly influencing the accuracy of fundamental measurements in fields such as high-precision metrology, atomic sensor applications, and quantum technologies. Saturation absorption spectroscopy (SAS) is one of the most effective techniques for achieving high spectral stability, as it enables laser frequencies to be locked to atomic resonances. This technique exploits the nonlinear interaction between a weaker probe beam and a stronger pump beam within an atomic vapor cell. By eliminating Doppler broadening, SAS allows well-defined hyperfine transitions to be resolved, providing a reliable optical frequency reference. This study aims to optimize laser frequency stabilization using the SAS technique by investigating the effects of laser light polarization, temperature of Rubidium (Rb) atomic vapor cell, and pump-probe power adjustments.

Introduction

Saturation absorption spectroscopy (SAS) is a powerful technique used to achieve Doppler-free spectroscopy by locking laser frequencies to well-defined atomic transitions. In conventional atomic absorption spectroscopy, Doppler broadening limits spectral resolution due to the thermal motion of atoms [1]. SAS overcomes this limitation using a pump-probe configuration, where a strong pump beam saturates a specific velocity group of atoms, and a weaker counter-propagating probe beam detects the resulting transparency window. This interaction produces sharp, stable resonance peaks corresponding to the natural atomic transition. Laser stabilization based on SAS is crucial for high-precision metrology, atomic clocks, and atomic sensor technologies.

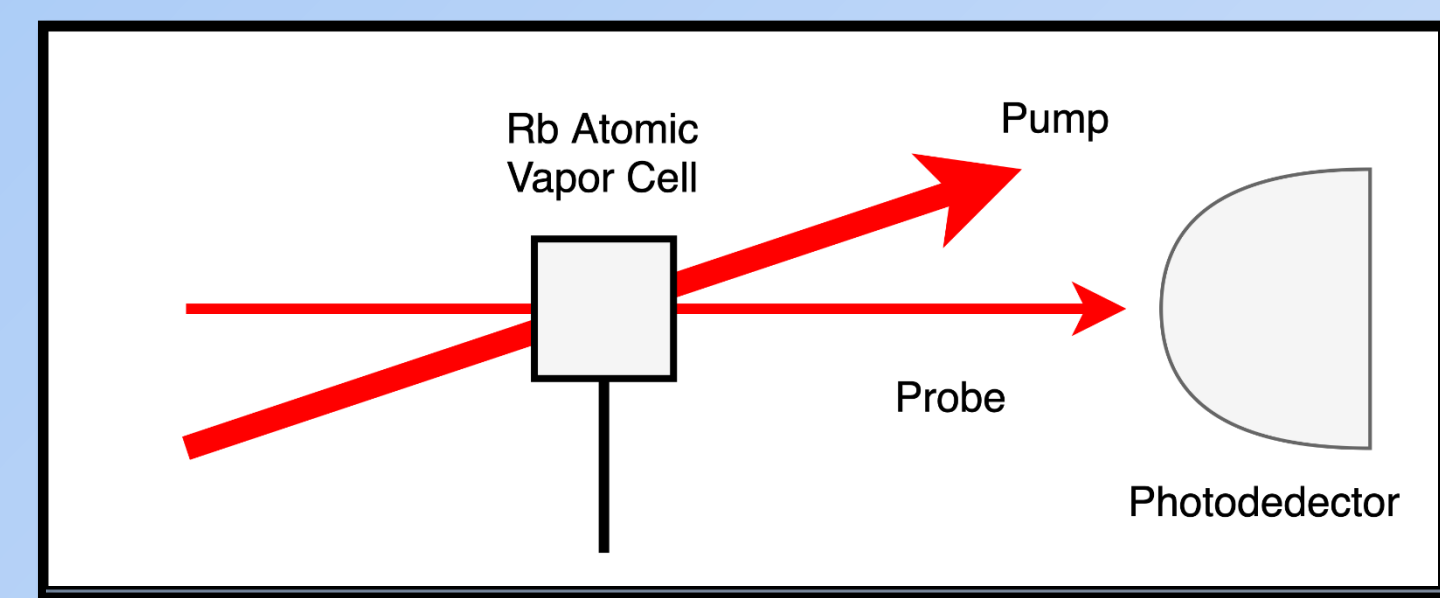
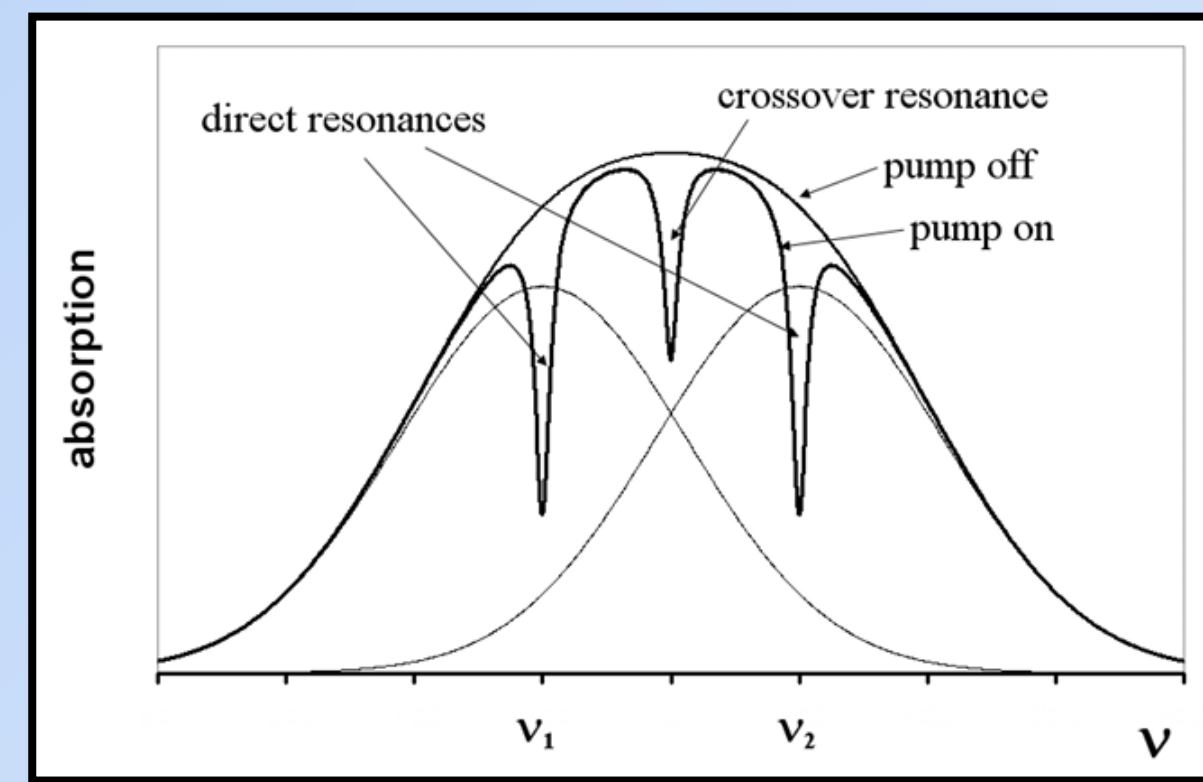


Fig. 1 Pumping effect for Absorption [2]



Optimizing experimental parameters such as light polarization, vapor cell temperature, and pump-probe power levels is essential for enhancing signal contrast and frequency stability. By refining these aspects, SAS provides a reliable optical frequency reference, contributing to advancements in precision measurement and quantum technologies.

Conclusion

The absorption spectra of atomic transitions were examined by changing the polarizations of the pump and probe laser beams. In Fig. 3, the change in the amplitudes of atomic transitions in different polarization states of the pump and probe laser beams was observed.

Another measurement performed is related to the temperature of the cell. Atomic transitions were examined by increasing the cell temperature at certain intervals. Since the atomic density in the cell increased as the temperature increased, the probe laser light was completely absorbed and this caused the atomic transitions to disappear after a certain temperature value. The results obtained from the experimental set-up support the theoretical expectation. In particular, the result obtained at 130 °C in Fig. 4 is consistent with the expected results.

In Fig. 5, it was observed that the linewidths of atomic transitions increased with the increasing power of the probe laser beam at constant value of pump laser beam power.

The result obtained from the spectroscopy study shows that the atomic density in the excited level changes depending on the polarization, density and cell temperature of the laser beams.

Experiment

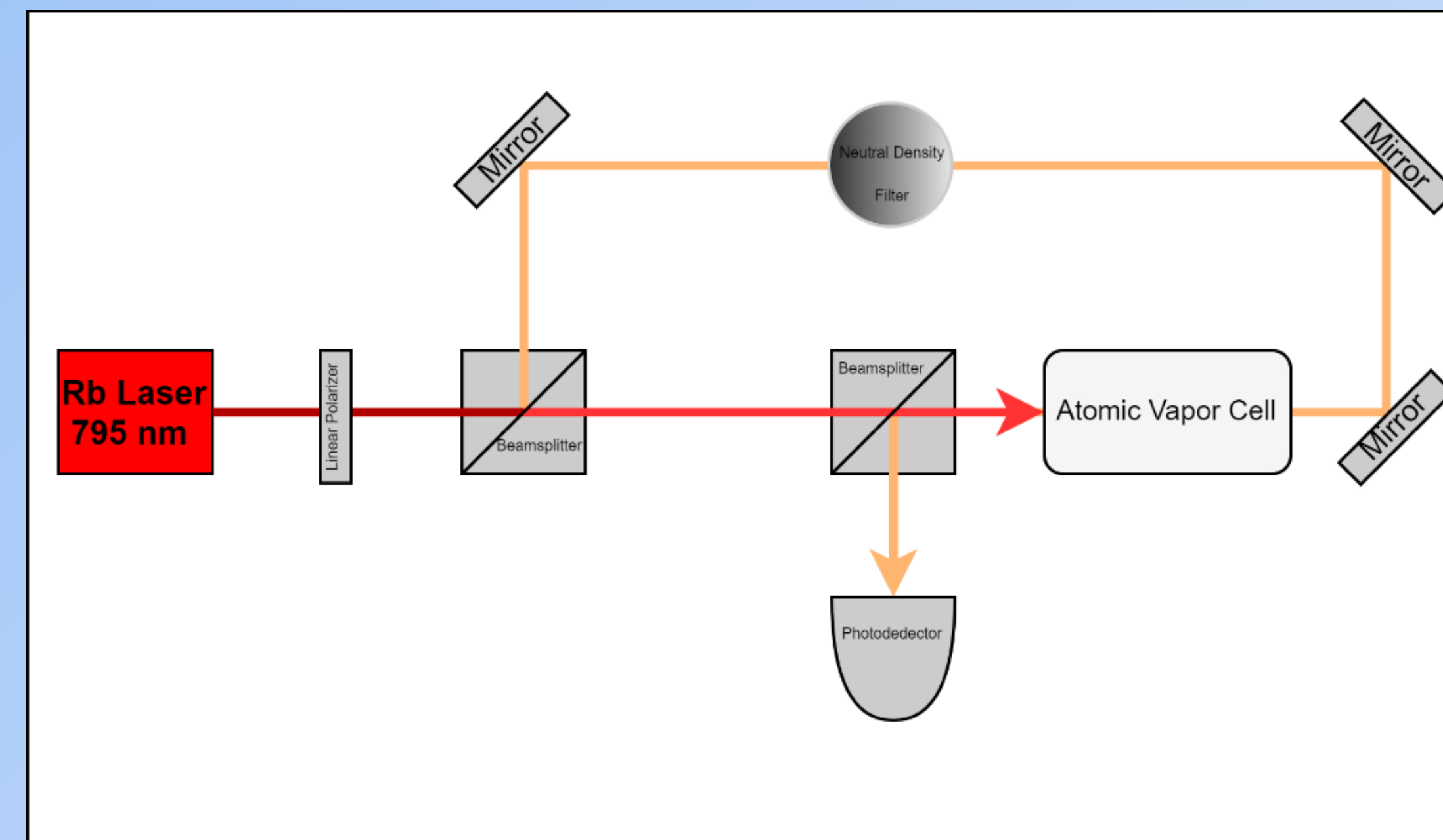


Fig. 2 Saturation Absorption Spectroscopy Optical Set-up

Laser light from a 795 nm Rubidium distributed Bragg reflector (DBR) laser passes through a linear polarizer to become linearly polarised. Then, the linearly polarised laser light splits by 90:10 (Transmitted : Reflected) beamsplitter into pump and probe beams respectively to create a higher intensity pump beam and a weaker probe beam. Continuously variable neutral density filter is used in order to control the probe beam power. Pump and probe beams are intersected inside the Rb atomic vapor cell on which a heater is mounted. Pump beam excites the Rb atoms to higher energy level and selectively saturates a specific velocity group of atoms are resonant with the laser frequency. Probe beam interacts with the same velocity class of atoms as the pump beam. When saturation occurs due to the pump, absorption of the probe beam decreases, creating a narrow Doppler-free absorption feature (Lamb dip) in the probe transmission spectrum received by the photodetector.

Results

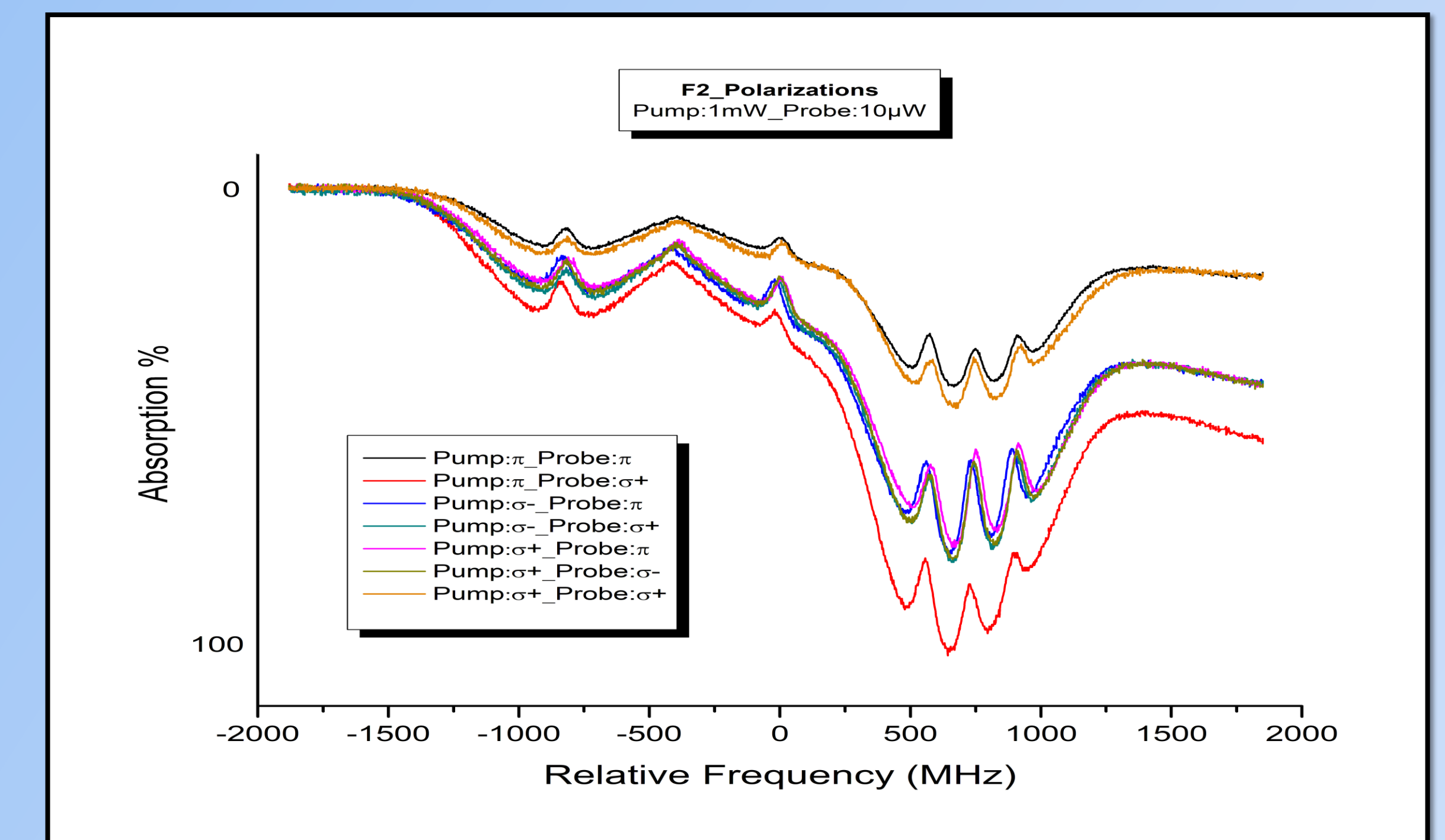


Fig. 3 Rb D1 Line F2 Transitions for different pump-probe polarizations

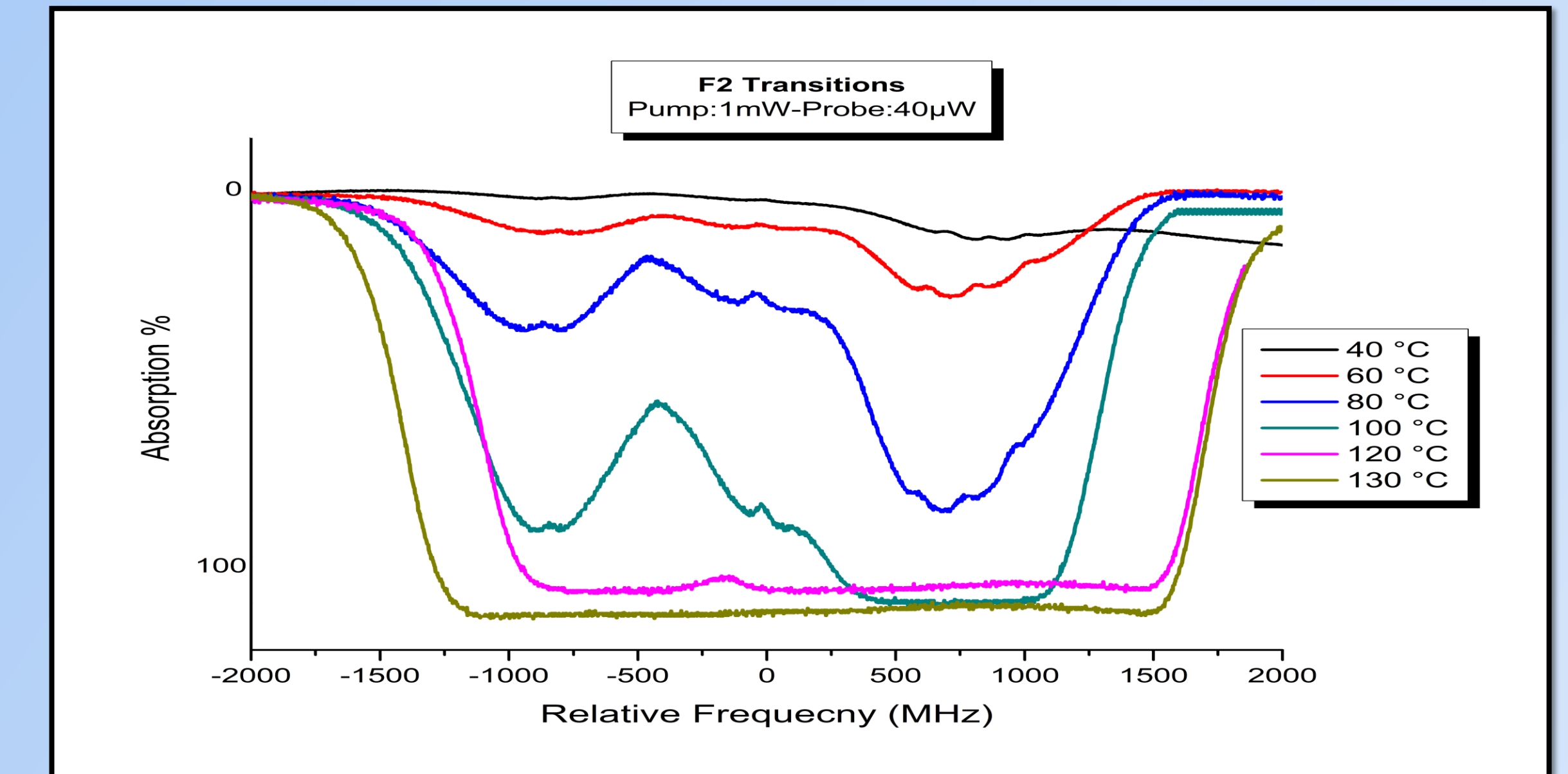


Fig. 4 Rb D1 line F2 Transitions for different temperature values

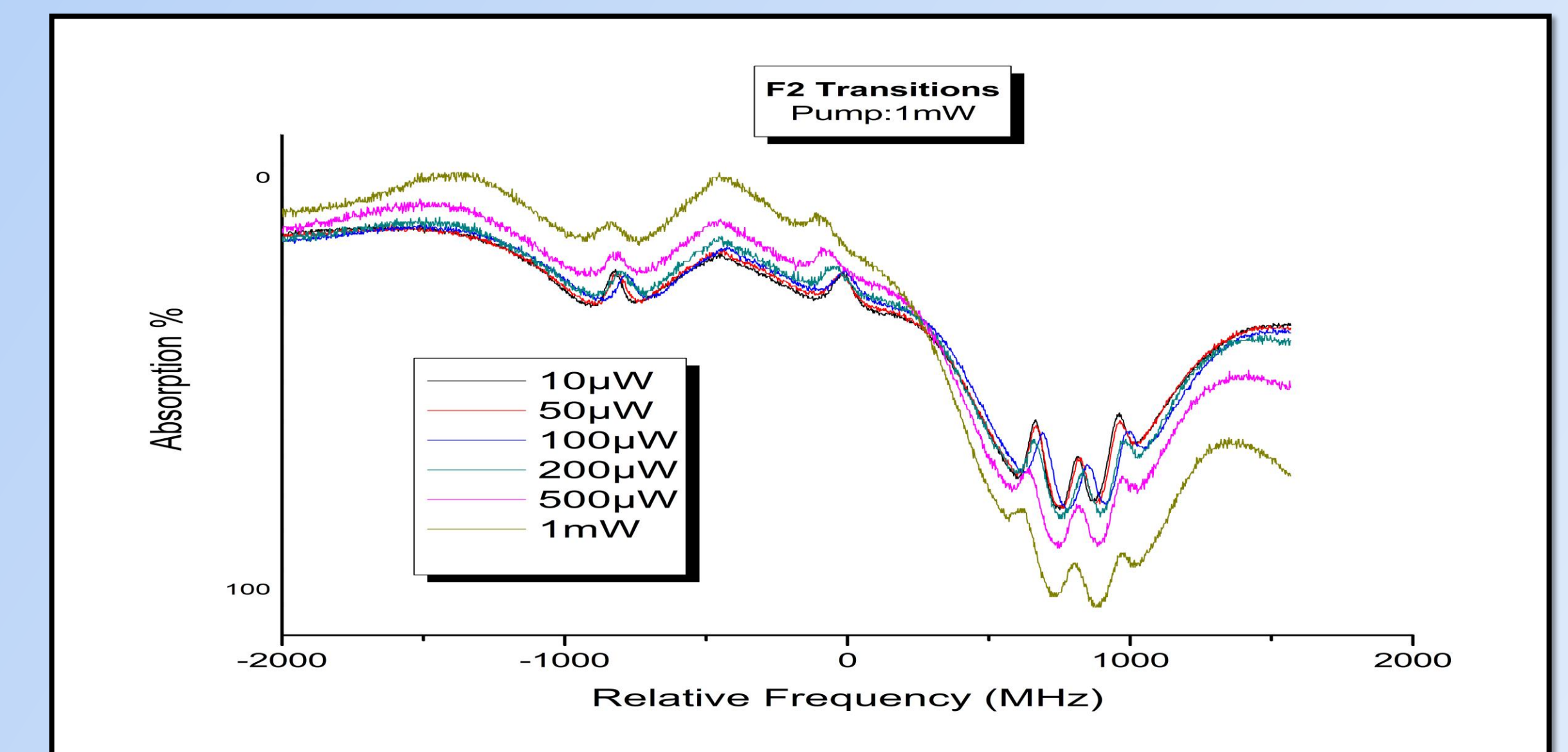


Fig. 5 Rb D1 Line F2 Transitions for different probe beam power

References

- [1] Daryl W. Preston, Doppler-free saturated absorption: Laser Spectroscopy. (1996)
- [2] University of Florida — Department of Physics