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High resolution laser spectroscopy of extremely thin Cs-vapour layers

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1. INTRODUCTION

Recently the high resolution spectroscopy of thin alkali-vapour layers has been made possible through the development of Extremely Thin Cells [1]. The vapour-layer thickness L can be precisely controlled in an interval around the wavelength λ of the irradiating laser light. Interesting coherent effects are observed in absorption profiles changing their width periodically, with minima at L = (2n+1) λ/2 (n - integer) [2,3]. At the same time the width of the fluorescence profiles increases monotonically with L. Well-resolved and good contrast sub-Doppler resonances in absorption and fluorescence have been obtained.

Here we present experimental and theoretical study of absorption and fluorescence spectra on the D_2 line of Cs-atomic-layers with thickness L = mλ (where m = 0.5, 1, 1.5, 2, 2.5, 3), when irradiated by frequency tunable single-frequency diode laser light. Interesting peculiarities, depending on the light intensity, occur when the vapour layer thickness is approaching the wavelength of the irradiating laser light, which can be used for investigation of the thin plasma layers as well.

2. EXPERIMENTAL RESULTS

For the experiment a single-frequency extended cavity diode laser is used and its FWHM is about 20 MHz. The frequency of the laser light is scanned over the two groups of hf transitions within the D_2 line of Cs (starting from ground-state levels with quantum numbers $F_g = 3$ and $F_g = 4$). The beam is sent normally to the ETC, whose design is similar to that described in [1]. The transmission and the fluorescence are measured in dependence on the laser frequency, for different cell thicknesses and different intensities of the light.

In Fig.1, the transmission spectrum of the hyperfine transitions $6S_{1/2}(F_g = 4) \rightarrow 6P_{3/2}$ ($F_e = 3, 4, 5$) is presented, for two different irradiating intensities and L = mλ. One can see that in case of m=0.5, 1.5, 2.5, Dicke narrowing of the hf transitions (better pronounced for low light intensity) is obtained due to the absorption enhancement in the transition center relative to that in the wings [2,3]. For m=1,2,3, the coherent Dicke narrowing is infringed and because of the Doppler broadening the hf structure is not resolved at low light intensity. However, well pronounced narrow dips of reduced absorption, centered at the hf transitions are observed at higher intensity. The reason is that the processes saturation (for all transitions) and optical pumping (for the open transitions) can be completed only for atoms with large enough time of interaction with the laser light i.e. for the atoms flying nearly parallel to the cell walls. This gives rise to highly velocity-selective dips in the absorption spectra, which amplitude increases with increasing the power density.

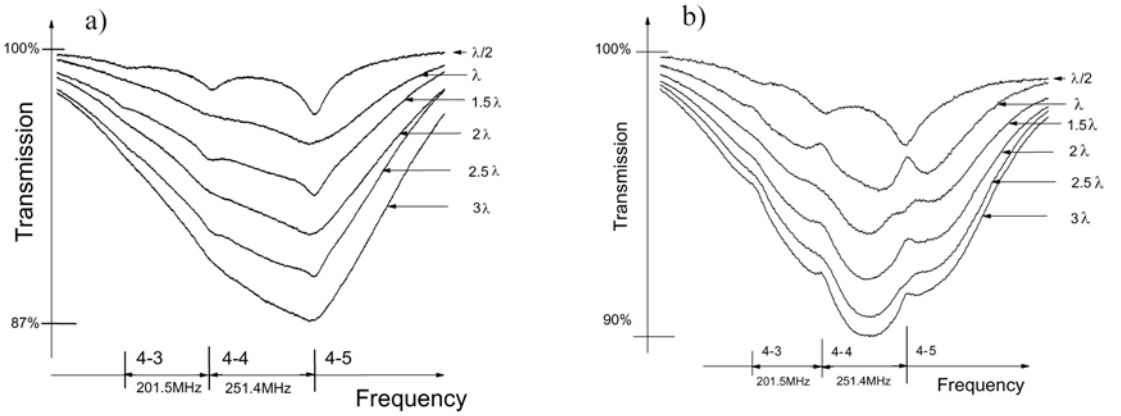

Figure 1: Transmission spectra for Fg = 4 set of transitions, for low (a, 0.2 mW/cm^2) and high (b, 20 mW/cm^2) light intensities.

Unlike the absorption case, for the ETC fluorescence spectra (Fig. 2) the contribution of the faster atoms with interaction time enough for absorption of a photon but not enough for its subsequent release will not appear in the signal. Here at higher m, the open transitions start to undergo optical pumping and reduced-fluorescence dips appear at the centre of transitions.

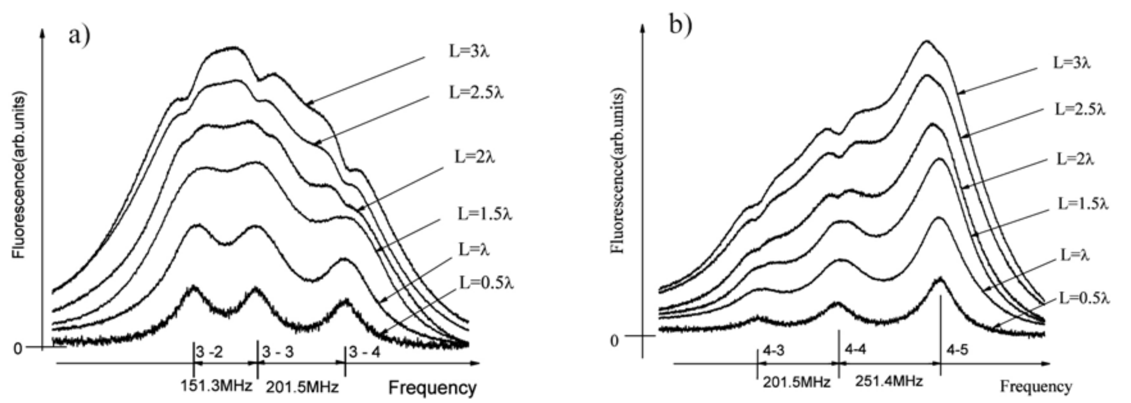

Figure 2: Fluorescence spectra for Fg = 3 (a) and Fg = 4 (b) sets of transitions, the light intensity is of 50 mW/cm^2.

The closed $F_g = 4 \rightarrow F_e = 5$ transition does not show a measurable dip in the fluorescence.

3. THEORETICAL INVESTIGATION

The used theoretical model is based on the Optical Bloch Equations for two-level system (closed and open) [4]. For both open and closed transitions, the absorption spectra calculated at low (Fig.3, 0.2mW/cm^2) light intensity shows the collapse (for m=1,2,3) and revival (for m=0.5, 1.5, 2.5) of Dicke-type coherent narrowing. When the irradiating laser light intensity increases (20mW/cm^2) and L>λ/2, a well pronounced dip in the absorption is obtained for the

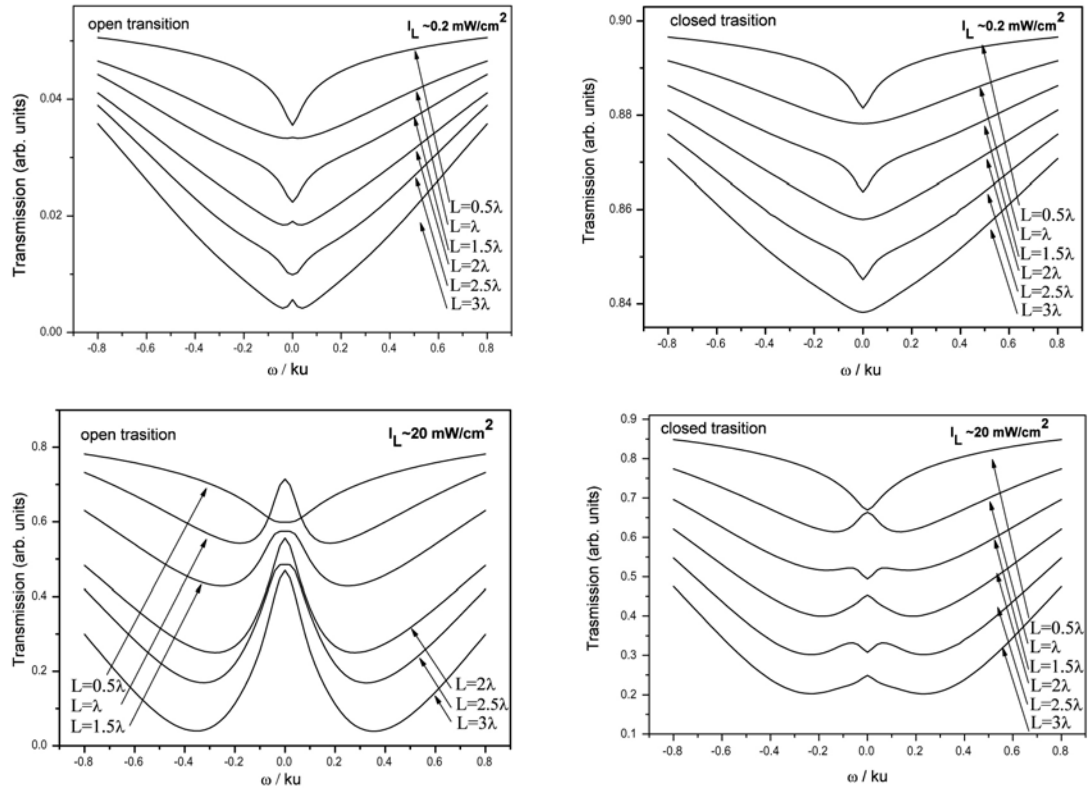

Figure 3: Theoretical calculations of the absorption spectra for open and closed transition respectively at low and high laser light intensity

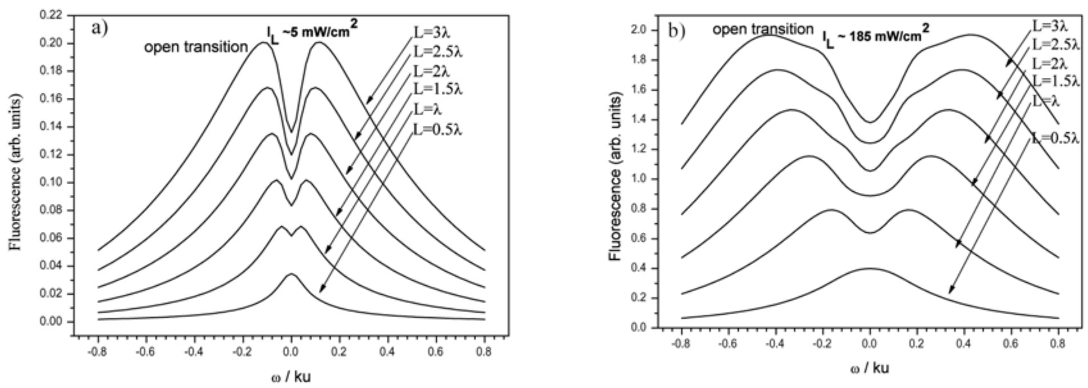

Figure 4: Theoretical calculations of the fluorescence spectra for open transition at low and high laser light intensity

open transition, while for the closed one the coherent Dicke peak (at m=1.5,2.5) is accompanied by some drop in absorption (Fig. 3, 20mW/cm^2).

At low power, the width of calculated fluorescence increases monotonically with the cell width. For the open transitions a narrow dip in the fluorescence (Fig. 4a) appears (superimposed on the top of the sub-Doppler-width fluorescence profile) which enhances its amplitude with m. At significantly higher light power (Fig.4b), the shape of the reduced fluorescence dip is more complex. Note, that although the theory qualitatively well describes the experimentally observed peculiarities, however the quantitative agreement is not satisfactory. Thus, further theoretical study is needed.

4. CONCLUSION

We have studied the absorption and fluorescence spectra of Cs confined in ETC at high intensity irradiation as compared to the low-intensity regime by means of a narrow-band ECDL light. For different laser intensities and m=0.5, 1.5, 2.5, in the absorption spectra the coherent Dicke narrowing is obtained, while for m=1, 2, 3 the hf structure is not resolved. Under high-intensity irradiation in the second case narrow dips of reduced absorption are observed, related to velocity selective optical pumping and saturation. In the fluorescence at low power, we observe well resolved fluorescence profiles. For high laser intensity for the open transitions narrow reduced-fluorescence dips superimposed on the fluorescence profiles are observed. The theoretical modelling is in qualitative agreement with the experimental observations, while quantitative one in some cases is not satisfactory.

The presented results contribute to the further advancement in fundamental studies of saturation and optical pumping in extremely thin vapour layers with possible further application in plasma study.

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