Multi Bennett holes and spectral hole burning

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Femtosecond laser frequency comb may have a very interesting influence on the velocity distribution of atoms in a vapor, due to the multiple frequency modes that are in resonance interaction with velocity groups separated by the mode separation equal to c/2L, where c is the velocity of light and L is the laser cavity length.

Bennett holes

Bennett holes appear whenever the cw laser within the Doppler profile interacts with specific velocity groups of atoms in the vapor. If several laser lines are within the Doppler profile, they will dig several Bennett holes. The application of the femtosecond laser frequency comb (or optical frequency comb) means that the ensamble of atoms will experience the short pulse train in the time domain, which in the frequency domain possess frequency comb structure. There is a very complex optical pumping procedure which transform the ground level populations into the needle like populations of the different velocity groups [1]. In the collisionless regime the cw laser that probes the ground state velocity populations brings about the hyperfine components shown in the lower panel of Fig. 1.

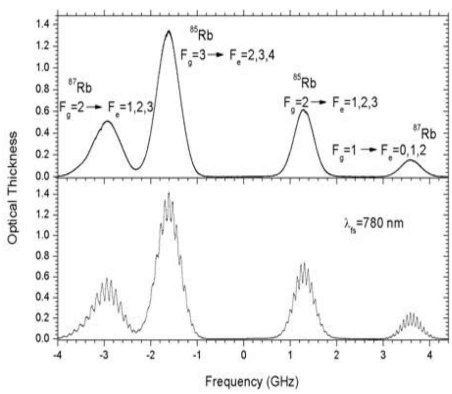

Figure 1. Doppler profiles of the hyperfine components of both rubidium isotopes (upper panel), and the modified profiles as a consequence of the resonance interaction with the optical frequency comb.

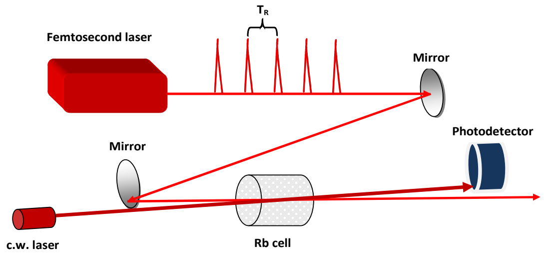

Figure 2. The simple experimental scheme

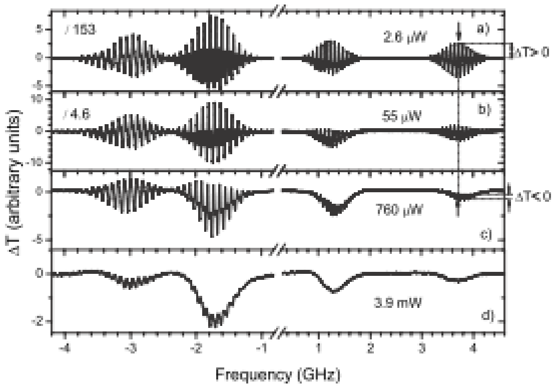

Figure 3. The dependence of the probe laser transmission modulations ΔT on the probe laser output power. The femtosecond laser is tuned to 795 nm, with 600 mW of average output power. The probe laser is scanned across $5^2S_{1/2} \rightarrow 5\,^2P_{3/2}$ absorption lines at 780 nm.

However, if the cw laser increases the power the contrast of the needlelike structure disapears, meaning that the atoms do not "feel" the pulse train anymore, except pulse by pulse excitation without any coherence effects [2].

In the same manner the coherent accumulation of populations and coherences disappear if the collisions among atoms take place at elevated temperatures, when the density of atoms increases [3].

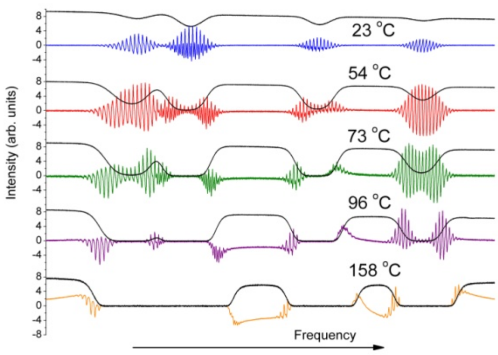

Figure 4. Modulation dependence on the Rb vapor temperature (atom concentration)

Quite generally in order for the frequency comb to appear ”visible” in an experiment we need resonance homogeneous broadening of the spectral transition in a system and another mechanism of broadening that has inhomogeneous character. Such a situation may be found in some transparent materials (e.g. crystals) with doped rare earth elements. The latter are called impurity centers, which consist of one doped atom, ion or molecule and its closest surrounding.

At very low temperatures many spectral transitions are well resolved, but each doped rare earth atom has a different surrounding, which means that the spectral transitions will be slightly shifted. Considering that all rare earth atoms have a different surrounding host atom structure, we shall end up with the resonance transitions distributed over the final profile given by the inhomogeneous broadening. In this way a similar situation is realized like in the above described case of rubidium atoms in a vapor phase. However, in the later case the inhomogeneous broadening is represented by the atom velocity distribution, whereas in the former case the local electric field from the surrounding atoms will form an inhomogeneous broadening effect. Unfortunately, the effect of coherent accumulation of populations and coherences could be observed only at liquid helium temperatures, whereas wishful case would be to study those effects at room temperature materials. Selective bleaching of the inhomogeneously broadened absorption band consisting of narrow homogeneous absorption lines is called spectral hole burning (SHB).

The solid state materials with doped rare earth atoms may be now used for addressing storage of information. This is a very vivid field of present investigation in many groups over the world [4, 5]. The storage capacity is enormous. The ultimate number of bits that can be recorded in a small volume of the material is given by the ratio between the inhomogeneous and homogeneous line width. This number may exceed one milion! The most interesting applications of spectral hole burning are in frequency-selective optical storage, time-space holography, EIT (electromagnetically induced transparency) and slow light studies.

References

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