Manipulation of the atom velocity with femtosecond laser frequency comb

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The frequency spectrum of the pulse train consists of a series of fringes separated by the pulse repetition rate. The fringes are regular in frequency space if the pulses in the pulse train have a defined phase relation relative to each other. In the systems where the atomic coherence relaxation time is longer than the pulse repetition period the atoms interact with the spectrum of the pulse train, and not with the spectrum of a single pulse. Mode-locked, phase-stabilized femtosecond (fs) lasers with high repetition rates produce stabilized wide-bandwidth optical frequency combs (regularly spaced series of sharp lines).

In our recent papers [1,2] we presented the observation of the velocity selective population transfer between the Rb ground state hyperfine levels induced by fs pulse train excitation. We developed a modified direct frequency comb spectroscopy (DFCS) which uses a fixed frequency comb for the ^{85,87}Rb 5 $^2S_{1/2} \rightarrow 5\ ^2P_{1/2,3/2}$ excitation (Tsunami mode-locked Ti:sapphire laser with pulse duration of ~100 fs and pulse repetition of 80 MHz) and a weak cw scanning probe (TOPTICA DL100, ECDL at 780 nm) for ground levels population monitoring. The Rb(5 $^2P_{1/2,3/2}$) excited atomic levels have the relaxation times greater than the fs laser repetition period. In the time domain this leads to population and coherence accumulation effects. This corresponds to the interaction of the Rb atoms with the fs frequency comb in the frequency domain. As a result, velocity selective excited state hyperfine level populations are obtained, i.e. the mapping of the frequency comb to the atomic velocity comb. Simultaneously, velocity selective optical pumping of the ground hyperfine levels is achieved. We measured the ^{85,87}Rb(5 $^2S_{1/2}$) hyperfine levels population by monitoring the 5 $^2S_{1/2} \rightarrow 5\ ^2P_{3/2}$ probe laser absorption. Modulations in the 5 $^2S_{1/2} \rightarrow 5\ ^2P_{3/2}$ hyperfine absorption line profiles are observed as a direct consequence of the velocity selective optical pumping induced by the frequency comb excitation. The ^{85,87}Rb 5 $^2S_{1/2} \rightarrow 5\ ^2P_{1/2,3/2}$ fs pulse train excitation of a Doppler broadened rubidium vapor was investigated theoretically in the context of the density-matrix formalism and the results are compared with the experiment. The agreement between theory and experiment is excellent. The dependence of the observed modulations upon the wavelength and power of the fs laser and external magnetic field was investigated experimentally. The expansion of the present investigation to the cesium case was performed.

We foresee an application of the results of this work in the field of spectroscopy of ultracold atoms and the atomic beam experiments. In the systems where Doppler broadening is negligible, by varying the comb optical frequency spectrum it is possible to directly manipulate the fractional populations of hyperfine ground state levels. In addition, we demonstrated that the frequency comb is suitable for velocity selective optical pumping which opens the way to a completely new scheme of laser cooling.

References:
[1] D. Aumiler, T. Ban, H. Skenderović and G. Pichler, Phys. Rev. Lett. **95**, 233001 (2005).
[2] T. Ban, D. Aumiler, H. Skenderović and G. Pichler, Phys Rev A, 73,043407 (2006).