Active optical frequency standards using cold atoms: perspectives and challenges

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We consider various approaches to the creation of a high-stability active optical frequency standard, a new type of optical frequency standard where the atomic ensemble itself produces a highly stable and accurate frequency signal. The concept of an active optical frequency standard (or the "clock laser") was recently proposed[1,2,3] and studied by several authors. The short-time frequency stability of such standards may overcome the stability of lasers stabilized to macroscopic cavities which are used as local oscillators in the modern optical frequency standard systems. Hereby, the creation of a high-stability active optical frequency standard and its exploitation as a local oscillator in passive optical frequency standard systems might improve the short-term stability of such systems and reduce the averaging time needed to reach a desired uncertainty.

The main idea is to create a "superradiant" laser operating deep in the bad cavity regime, where the decay rate of the cavity field significantly exceeds the decoherence rate of the lasing transition. Two main approaches towards the realization of an active optical frequency standard are: the optical lattice laser[1,2] and the atomic beam laser[3]. The first approach suggests using cold atoms with narrow optical transitions confined to the Lamb-Dicke regime inside an optical lattice potential as a gain medium to build the laser. The necessary population inversion can be realized by additional repumping fields, coupling the lower lasing state with some higher levels from which atoms decay to the upper lasing state. A prototype experiment using a Raman system to mimic a narrow linewidth optical transition[4] has demonstrated the general operation principle. The second approach is an atomic beam laser, where a continuous beam of atoms, previously pumped to the upper lasing state, passes through the cavity.

We consider the optical lattice laser, the atomic beam laser, and some alternative approaches to the creation of high-stability active optical frequency standards, and discuss the parameters of atomic ensembles necessary to attain the short-time frequency stability better than the best modern macroscopic cavities can provide. We consider also various effects critical for practical implementations, the main challenges and possible methods of overcoming them.

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