ac-Stark gradient echo memory in cold atoms

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The three-level Gradient Echo Memory has proven to be an efficient, flexible and robust quantum memory candidate. Even with a simple warm vapour cell we have demonstrated recall efficiencies up to 87% [1] and recall of pulses in arbitrary order [2] (See science report by Hosseini et al.). Our experiments to date indicate that we are limited by Doppler effects in our warm atomic gas. The three-level gradient echo system relies on the creation of a linear atomic frequency gradient along the length of the storage ensemble. This is currently achieved using a Zeeman shift induced by magnetic field coils, which have limited flexibility in terms of switching time and spatial precision.

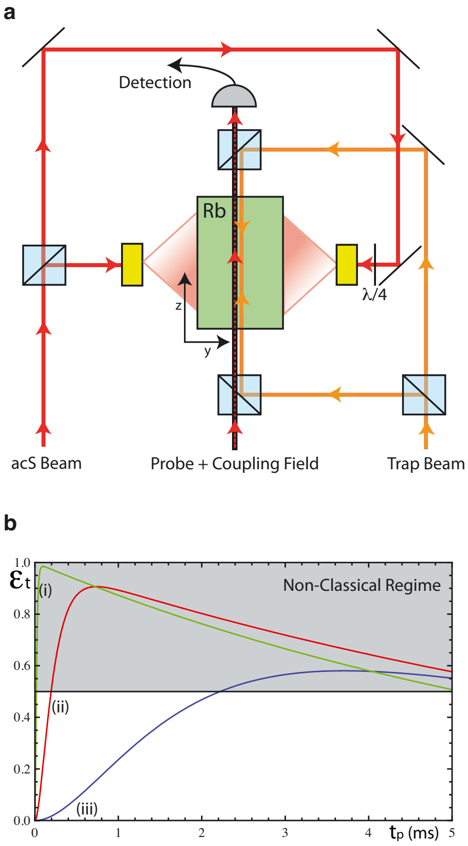

Fig. 1: a) A schematic of the ac-Stark shift system. The atomic frequency gradient is created for atoms held in an optical dipole trap. The Stark beams can be shaped using phase plates or spatial light modulators, or controlled in polarisation by Pockels cells. b) The modelled performance of the system for single pulse storage as a function of pulse length t_p for storage times of one pulse length and different ratios of control beam Rabi frequency to Ramen detuning = (i) 0.01, (ii) 0.003, and (iii) 0.001.

With these limitations in mind we modelled an alternative design for our three-level memory. We considered the use of an ac-Stark shift [3] in conjunction with a cold atomic ensemble in an optical dipole trap. In this system we imagine a laser field with an intensity gradient applied perpendicular to our signal field. The varying intensity of the field will create a varying ac-Stark shift along the length of the ensemble, as indicated in Fig.1(a). We can imagine switching the gradient either by using fields directed from either side of the memory or by switching the polarisation of the ac-Stark beam which, for carefully chosen magnetic levels in the atomic system, can also reverse the frequency gradient. Our modelling showed that, for ^{87}Rb, the best wavelength for the ac-Stark beam is around 810 nm where there is a local minimum in the scattering rate for the F=2, m_F=1 sublevel. While the frequency shift per Watt will vary depending on how the Stark beam is focussed, bandwidths of MHz are quite achievable with less than 10 W of power.

For physically reasonable parameters for dipole optical depth, scattering rates and beam intensities the modelled memory efficiency is shown in Fig.1(b) for different coupling beam powers. The model suggests that high storage efficiency is possible for long times in such a system. We anticipate investigating this system experimentally in the future.

References

[1] M. Hosseini *et al.*, Nat. Commun. **2**, 174 (2011).
[2] M. Hosseini *et al.*, Nature **461**, 241 (2009).
[3] B. Sparkes *et al.*, Phys. Rev. A **82**, 043847 (2010).