Broadband Optical Delay with Large Dynamic Range Using Atomic Dispersion

M. R. Vanner, R. J. McLean, A. I. Sidorov, P. Hannaford and A. M. Akulshin

ARC Centre of Excellence for Quantum-Atom Optics and Centre for Atom Optics and Ultrafast Spectroscopy, Swinburne University of Technology, Melbourne, 3122, Australia

Introduction

In both classical and quantum information processing there is an increasing need to controllably delay optically encoded information.

This can be achieved with slow light, where the group velocity of an optical pulse can be much less than the phase velocity, i.e.

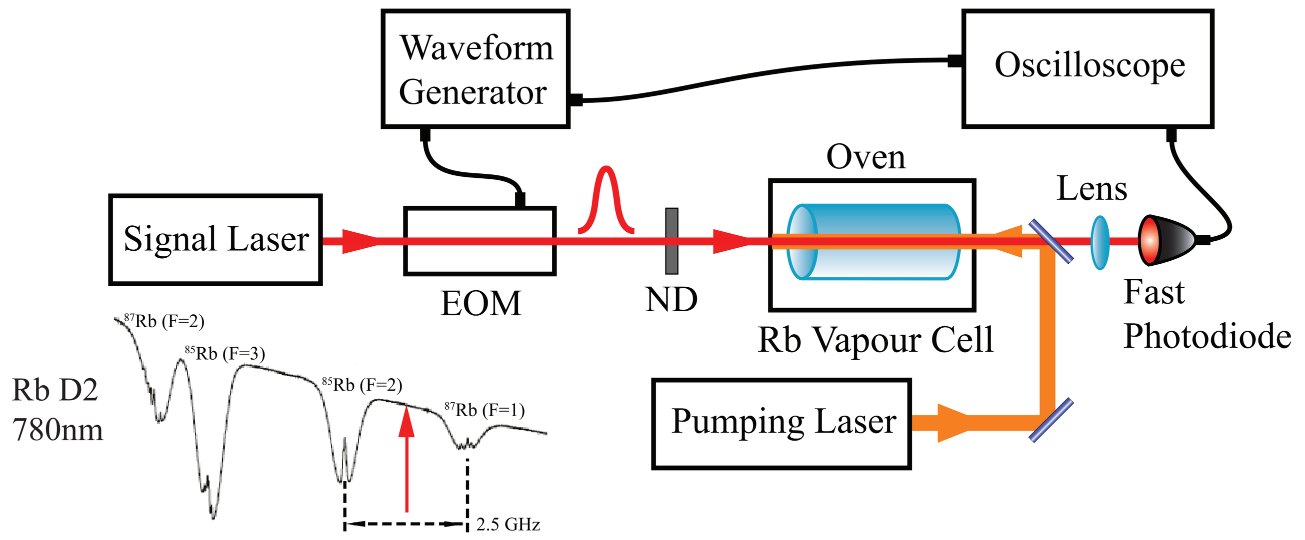
$$v_g = c/(n+\omega dn/d\omega) = d\omega/dk << c$$

The spectral width of the region of approximately linear positive dispersion must exceed the pulse bandwidth.

Electromagnetically induced transparency (EIT) based delay has been widely studied. The narrow spectral region and high dispersion mean large delays but long (μs) pulses.

In this work [1] we investigate tunable all optical delay using the intrinsic positive dispersion between pairs of absorption components within the rubidium D2 line [2]. Such a system gives lower dispersion than EIT, but the broad spectral window means shorter pulses can be used.

Experimental Setup



- Signal laser tuned between ^{85}Rb(F=2) and ^{87}Rb(F=1) D2 line components.
- 10ns pulses generated by EOM, propagate through heated cell, detected on fast photodiode.
- Optical pumping field counter propagates relative to pulses, tuned to D1 line.

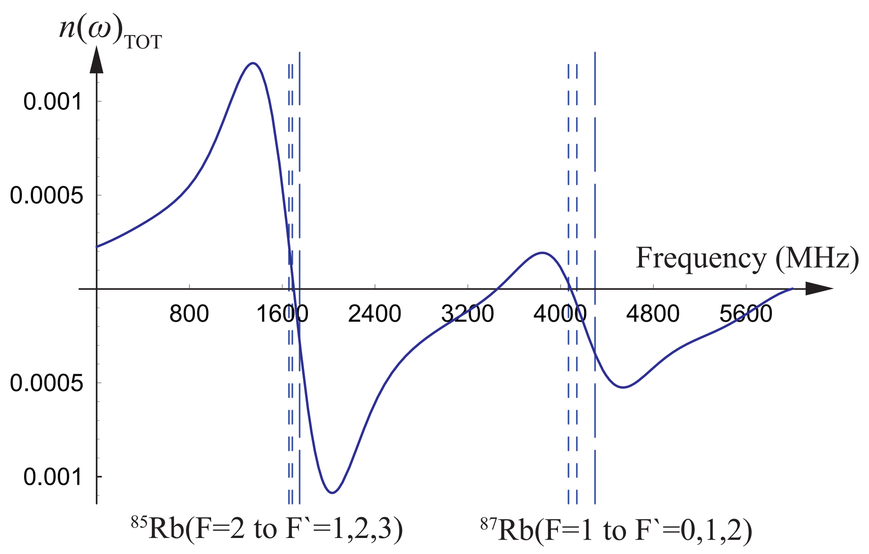
Numerical Model

Frequency dependence of absorption coefficient and refractive index modelled using numerical convolution of homogeneous and inhomogeneous profiles.

- Homogeneous component includes saturation.
- Profile calculated for the three transitions within each absorption component.

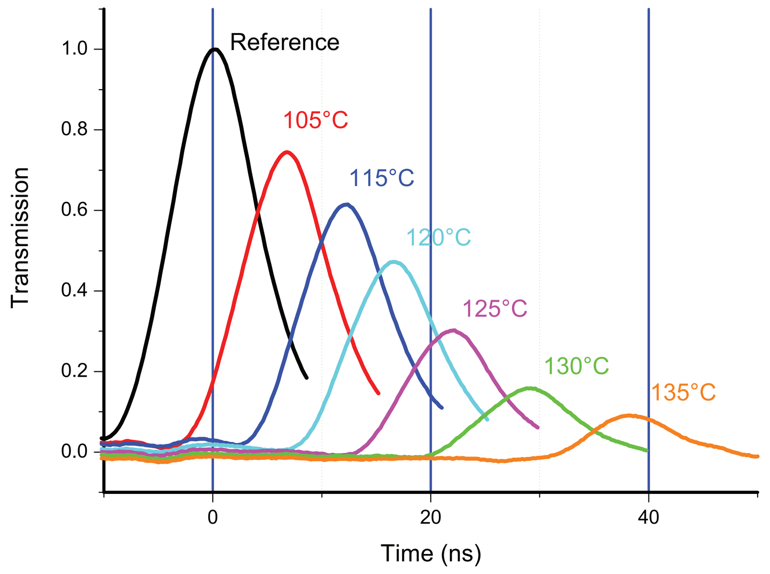
$$\alpha(\omega)_{TOT} = \alpha(\omega, S, T) * D(\omega, T)$$

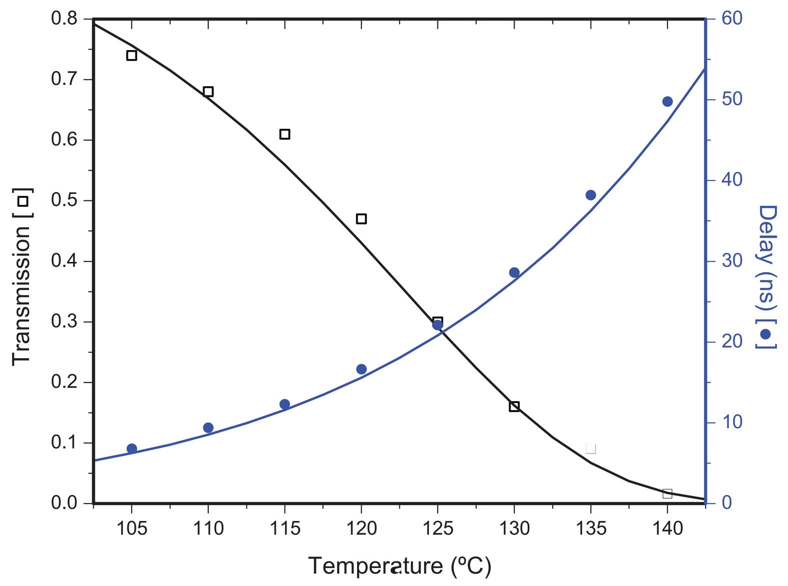
$$n(\omega)_{TOT} = n(\omega, S, T) * D(\omega, T)$$



Tunable all-optical delay

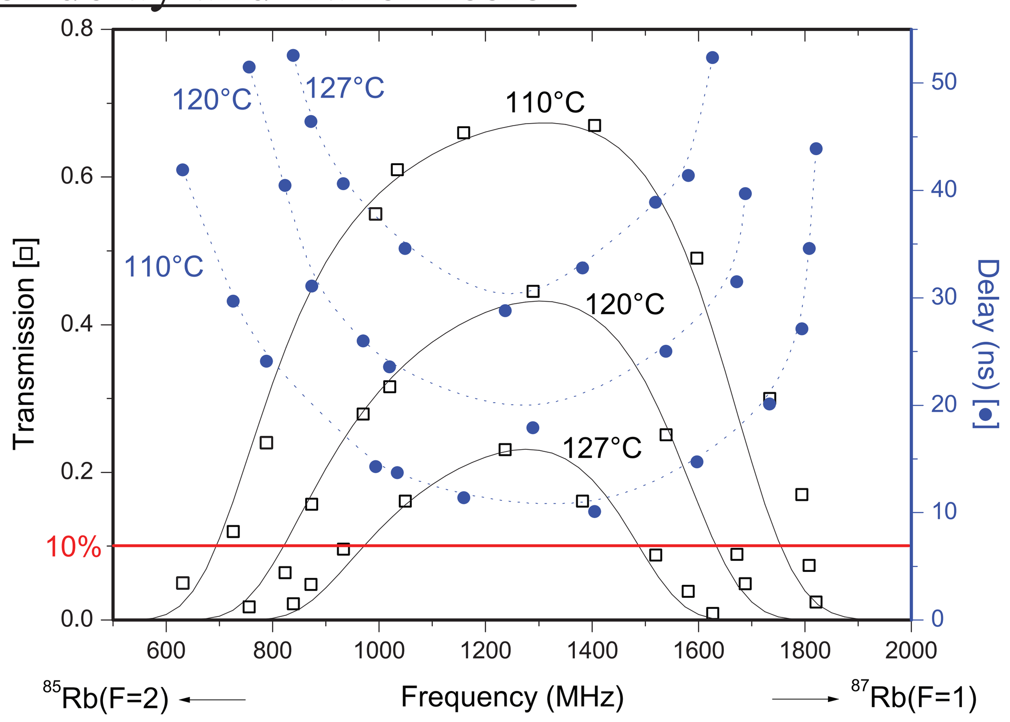
- As temperature increases, the delay increases by two mechanisms: atomic density increases and broadening of Doppler profile.
- Fractional delay (delay/pulse width) of 4.3 observed for 9% transmission.





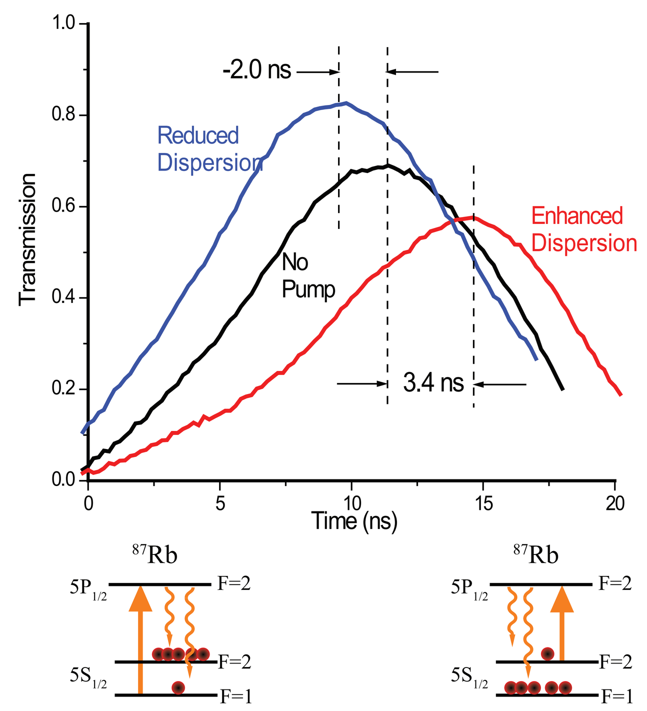
Frequency dependence of delay and transmission

- Usable bandwidth decreases with temperature.
- Saturation less in wings of absorption profile.

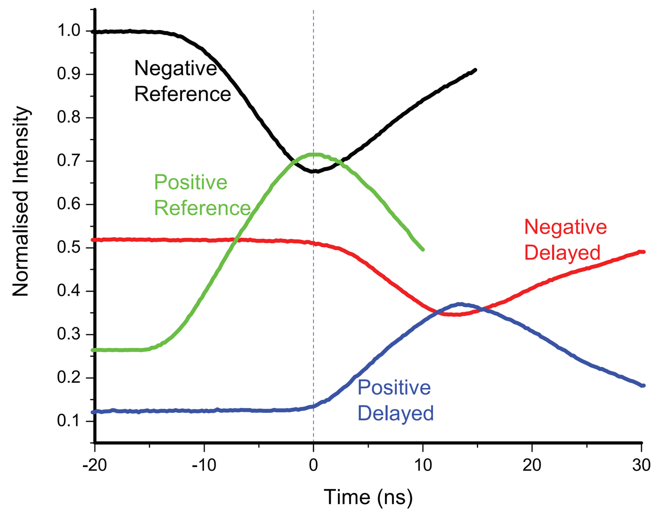


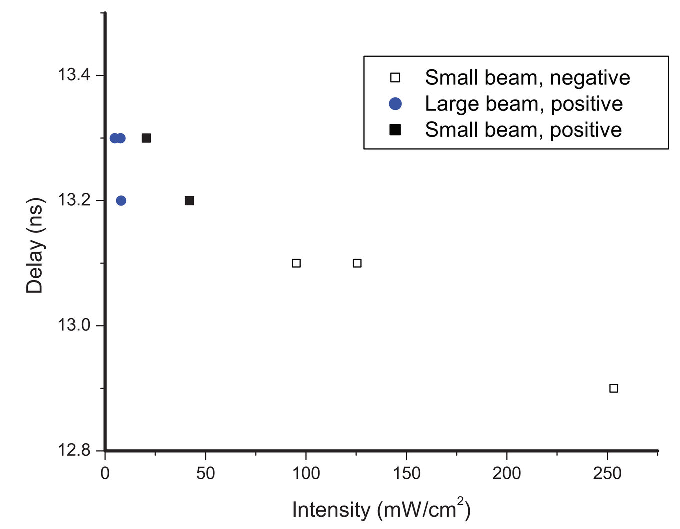
Controlling delay by optical pumping

- Temperature control: broad but slow control of delay.
- We use hyperfine optical pumping on D1 line to rapidly change ^{87}Rb(F=1) population - minimal change to ^{85}Rb(F=2)
- D1 line: greater longitudinal homogeneity, no cycling transitions.
- Delay reduced by 17.5%, increased by 25% of the pulse duration.



Intensity dependence of delay





- Positive and negative pulses used to determine the effect of intensity on delay. Delay reduces linearly at 1.8 ps/(mW/cm^2).
- Negative pulse shapes may be useful in other experiments such as those involving atomic coherence.

Conclusion

- Optical pulses of 9.3 ns duration (FWHM) with frequency tuned between the ^{85}Rb(F=2) and ^{87}Rb(F=1) components of the D2 line were delayed in a 10 cm vapour cell at 135°C by more than 40 ns (fractional delay 4.3) with approximately 10% transmission and low distortion. Observed fractional delay limited by pulse length that could be generated.
- Using absorption components of different isotopes for a tunable all-optical delay line allows optical pumping with a single pump laser to modify the interacting population of one component without modifying the other. Rapid tuning of the delay was obtained by optical pumping over a range of 43% of the unmodified pulse delay at 110°C.
- The observed delay and transmission with increasing temperature is in good agreement with our numerical model, as is the frequency dependence of transmission.
- Negatively shaped pulses are delayed similarly to positive pulse shapes. These were used to determine the intensity dependence of pulse delay.
- Such broadband optical delay lines may be used to delay quantum information encoded as weak coherent pulses or squeezed states.

References

[1] M. R. Vanner *et al*, in preparation.

[2] R. M. Camacho *et al*, "Low-distortion slow light using two absorption resonances," Phys. Rev. A **73**, 063812 (2006)