Electromagnetically-induced-transparency-based light storage in the short pulse regime

Introduction

- Electromagnetically induced transparency (EIT)
  - Transparency
    - Quantum interference (Autler-Townes Doublet)
  - Slow Light
  - Coherent Optical Memory
    - Classical information of light is preserved in atoms (ground state coherence) through EIT system. It should be concerned

\[
\frac{\text{Fractional delay (Optimization of storage efficiency)}}{\rho_3} = \frac{\tau_p}{\Delta \rho} = \frac{2.7}{\Gamma} \quad (\text{to assure the storage efficiency is more than 97%})
\]

Optical Bloch Equations:

\[
\begin{align*}
\dot{\rho}_{11} & = \frac{1}{2} \Omega_1 \rho_{21} + (\Delta - 2\gamma_2) \rho_{11} - i \omega_2 \rho_{11} \\
\dot{\rho}_{21} & = -\frac{1}{2} \Omega_2 \rho_{21} + (\Delta + 2\gamma_2) \rho_{11} + i \omega_2 \rho_{11}
\end{align*}
\]

where, \( \Omega_1 = \frac{\gamma_1}{\Gamma_1} \), \( \Omega_2 = \frac{\gamma_2}{\Gamma_2} \), \( \Delta = \omega_2 - \gamma_2 \).

Group velocity distortion

To ensure the fidelity between stored light and transmitted light, we can define classical fidelity (CF) [1]

\[
\begin{align*}
\text{Classical fidelity} (\text{CF}) &= \exp \left[ -\frac{\text{Area} \times \text{Transmission} \times \text{Rotation} \times \text{Phase Shift}}{\text{Output Width}} \right] \\
&= \exp \left[ -\frac{\text{Area} \times \text{Transmission} \times \text{Rotation} \times \text{Phase Shift}}{\text{Output Width}} \right]
\end{align*}
\]

Analysis

- By assuming \( \rho_{21} = 0 \), \( \gamma_2 = 0 \), \( \Delta \), \( \rho_3 \) is small, comparing with \( \gamma_2 \), the numerator of eq.(4) can be expanded as

\[
\text{Fidelity} (\text{CF}) = \exp \left[ -\frac{\text{Area} \times \text{Transmission} \times \text{Rotation} \times \text{Phase Shift}}{\text{Output Width}} \right]
\]

Conclusion

In summary, we studied the limit of light storage system. In short probe pulse regime, classical fidelity drops and the group velocity distortion become evident. Firstly, we quantitatively derive the deterministic factor for the stored-pulse width limit, which is directly correlated with optical depth. The higher the optical density is, the broader range of the accessible stored-pulse width is. To extend the limit of stored-pulse width, we have to increase the optical depth of the light storage system. High optical density reduces the limit of stored-field width. Secondly, we derive the deterministic factor for the stored-pulse width limit. Requiring CF to be more than 99 % with fixed \( \omega \), we proved that the input pulse duration is inversely proportional to \( \tau_p \).

The result highlights the significance of ultra-high optical depth in coherent optical memory processing. Augmenting optical depth of the EIT system seems to be a trend for the development of coherent optical memory. The significant breakthrough of the light storage system extends our knowledge of the optical coherent memory processing. Correlating classical with quantum fidelity provides us further understanding of quantum technology and bring possibilities of applications in memory processing.

Reference