Supplemental Document

OSA CONTINUUM

Fiber Bragg grating-electromagnetically induced transparent fast optical switch: supplement

NARGES SHAFII MOUSAVI,[1] PARVIZ PARVIN,[1,*] AND MARYAM ILCHI-GHAZAANI[2]

[1] *Photonics Engineering Group, Physics Dept., Amirkabir University of Technology, P.O. Box 15875-4413, Tehran, Iran*
[2] *Photonics and Quantum Technologies Research School, Nuclear Science and Technology Research Institute (NSTRI), P.O. Box 14399-51113, Tehran, Iran*
[*] *parvin@aut.ac.ir*

Supplement DOI: https://doi.org/10.6084/m9.figshare.14464449

Parent Article DOI: https://doi.org/10.1364/OSAC.415468

Supplementary section:

1. EIT Formalism

In the case of laser exposure, the Hamiltonian of Λ-type atoms is given by [50, 51, 55]:

$$H = -\frac{\hbar}{2}\begin{bmatrix} 0 & 0 & \Omega_p \\ 0 & -2(\Delta_p - \Delta_c) & \Omega_c \\ \Omega_p & \Omega_c & -2\Delta_p \end{bmatrix} \tag{1}$$

Note that $(\Delta_p - \Delta_c)$ is the total detuning parameter.

The density operator ρ consists of all state dynamics of the laser driven atomic system. The time-dependent density matrix equation is described by the Liouville equation, namely [45, 48, 49, 51]:

$$\frac{\partial \rho}{\partial t} = -\frac{i}{\hbar}[H, \rho] - i\hbar\Gamma\rho \tag{2}$$

where, Γ is the matrix of the damping coefficients. Then, density matrix elements can be obtained according to the following differential equations [48, 51]:

$$\dot{\rho}_{12} = i\rho_{32}\Omega_p - i\rho_{13}\Omega_c + \rho_{12}(i(\Delta_p - \Delta_c) - \gamma_{21}) \tag{3}$$

$$\dot{\rho}_{13} = i(\rho_{33} - \rho_{11})\Omega_p - i\rho_{12}\Omega_c + \rho_{13}i(\Delta_p - \gamma_{31}) \tag{4}$$

$$\dot{\rho}_{32} = i(\rho_{33} - \rho_{22})\Omega_c + i\rho_{21}\Omega_p - \rho_{32}i(\Delta_c + \gamma_{32}) \tag{5}$$

Including the following conditions [48, 51]:

$$\rho_{ij} = \rho_{ji}^{*} \tag{6}$$

$$\rho_{11} + \rho_{22} + \rho_{33} = 1 \tag{7}$$

Here, the total decay rates are added phenomenologically in the density matrix equations. On the other hand, the steady-state condition leads to simplifying the relations, such that $\dot{\rho}_{13} = \dot{\rho}_{12} = \dot{\rho}_{23}$ or in the case of the weak probe laser $(\frac{\Omega_p}{\Omega_c} \ll 1)$, considering $|1\rangle$ as an initial state, the atomic population remains almost invariant in this state implying $\rho_{11} \cong 1$, and because of continuity principle ($\rho_{11} + \rho_{22} + \rho_{33}=1$) then $\rho_{22} \approx \rho_{33} \approx 0$. Thus, the steady state solution is obtained as below [48, 51]:

$$\rho_{31} = \Omega_p \frac{-(\Delta_p - \Delta_c) - i\gamma_{21}}{\Omega_c^2 + (\gamma_{31} - i\Delta_p)(\gamma_{21} + i(\Delta_p - \Delta_c))} \tag{8}$$

Moreover, the time-dependence solution for ρ_{12} and ρ_{31} are given as below [50, 65]:

$$\rho_{12} = -\frac{i\Omega_c e^{i\Delta_c t}}{\gamma_{21} + i2(\Delta_c - \Delta_p)}\rho_{13} \tag{9}$$

$$\rho_{31} = -\frac{i\Omega_p e^{i\Delta_p t}}{(\gamma_{31} + i2\Delta_p)} + \frac{i\Omega_c e^{i\Delta_c t}}{(\gamma_{31} + i2\Delta_p)}\rho_{21} \tag{10}$$

Meanwhile, the polarization of the atomic medium induced by the applied field is given by [50, 66]:

$$P(z) = N/V\,(\mu_{13}\rho_{13}e^{-i\omega_{31}t} + \mu_{23}\rho_{23}e^{-i\omega_{32}t} + c.c) \tag{11}$$

Where, N is the density of the EIT nanocrystals in volume V.

In general, the linear susceptibility contains most of the important features of EIT [50, 55, 65]:

$$\chi = \chi' + i\,\chi'' \tag{12}$$

Where, χ' and χ'' are real and imaginary parts of susceptibility $\chi = \chi' + i\,\chi''$, correlated to the phase shift per unit length and the absorption coefficient of the pulsed laser field, respectively.

The real and imaginary parts of the susceptibility are [51]:

$$\mathrm{Im}(\chi) = \frac{N\,\mu_{13}^2}{\varepsilon_0\hbar}\frac{\gamma_{31}(\gamma_{21}^2 + (\Delta_p - \Delta_c)^2) + \gamma_{21}\Omega_c^2}{(\Omega_c^2 + \gamma_{31}\gamma_{21} - \Delta_p(\Delta_p - \Delta_c))^2 + (\Delta_p\gamma_{21} + (\Delta_p - \Delta_c)\gamma_{31})^2} \tag{13}$$

$$\mathrm{Re}(\chi) = \frac{N\,\mu_{13}^2}{\varepsilon_0\hbar}\frac{(\Delta_p - \Delta_c)(\Delta_p(\Delta_p - \Delta_c) - \Omega_c^2) + \Delta_p\gamma_{21}^2}{(\Omega_c^2 + \gamma_{31}\gamma_{21} - \Delta_p(\Delta_p - \Delta_c))^2 + (\Delta_p\gamma_{21} + (\Delta_p - \Delta_c)\gamma_{31})^2} \tag{14}$$

2. Steps of model

Fig. S.1 summarizes the sequential modeling steps of EIT doped FBG as a fast optical switch.

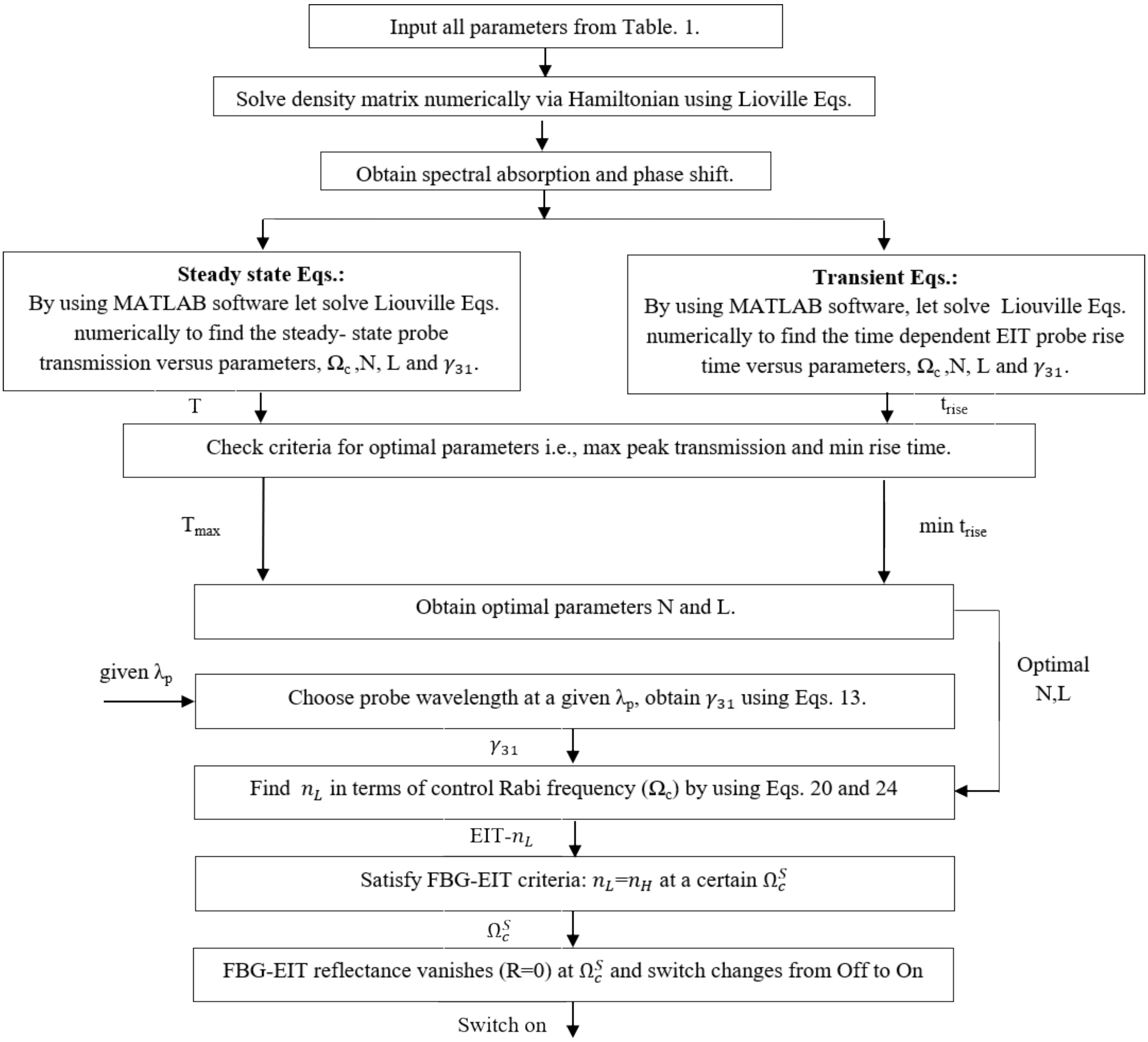

Fig. S.1. Sequential steps to model EIT doped FBG as a fast optical switch to find optimal parameters (Ω_c, N, L and γ_{31}) based on the criteria: max peak transmission, min rise time where FBG-EIT satisfies $n_L = n_H$ condition at $\Omega_c = \Omega_c^S$