Reply to "Comment on 'Large enhancement of four-wave mixing by suppression of photon absorption from electromagnetically induced transparency' "

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Buffa *et al.* [1] present a study of a four-wave mixing (FWM) scheme analyzed by us [2] and conclude that the FWM efficiency is better without electromagnetically induced transparency (EIT). We note that their calculations are based on the derivations and equations in [2] and the conclusion is valid only for an optically thin medium, in which the linear absorption loss is not dominant.

It is well known that EIT is a channel-opening technique to produce a transmission window in an otherwise optically thick medium, in which a weak probe light is heavily attenuated without EIT [3]. Therefore, EIT is obviously not needed for the FWM scheme [2] if the medium is optically thin and the absorption of the probe light is small. However, in an optically thick medium, the resonant single-photon absorption is dominant without EIT (the resonant two- and three-photon absorption are also present), and the probe light is completely absorbed, which effectively shuts down the FWM process. With EIT, the single-photon absorption as well as the nonlinear absorption is suppressed and near 100% of the (probe) light contributes to the FWM process. The FWM efficiency under such conditions becomes much greater than the one without EIT.

Figures 1 and 2 clearly show that the FWM process is assisted by EIT in an optically thick medium. Notice that $\kappa_{0j}=\gamma_j N\sigma_j/2(j=2,4)$. Here N is the atom concentration, γ_j is the decay rate, and σ_j is the resonant absorption cross section. An optically thick (thin) medium corresponds to a large (small) $\kappa_{0j}z \propto N\sigma_j z(j=2,4)$. Specifically for the FWM scheme without EIT, the medium can be defined as thick when the distance is greater than the critical distance z_c, where the FWM efficiency drops down to the value η_{max}/e (η_{max} is the maximum FWM efficiency and $z_c \approx 6$ mm for the parameter regime in Fig. 1). To overcome the dominant linear and nonlinear absorption in the optically thick medium, one can utilize EIT to suppress the light absorption, which leads to a large increase of the FWM efficiency in comparison with the FWM efficiency without EIT, as shown in Figs 1 and 2 for $z \geqslant 8$ mm.

It is noted that Fig. 1 in Ref. [1] plots the total energy of the generated FWM field $\int |W_m(\omega)|^2 d\omega$ versus the medium length without specifying the pulse shape of the probe field

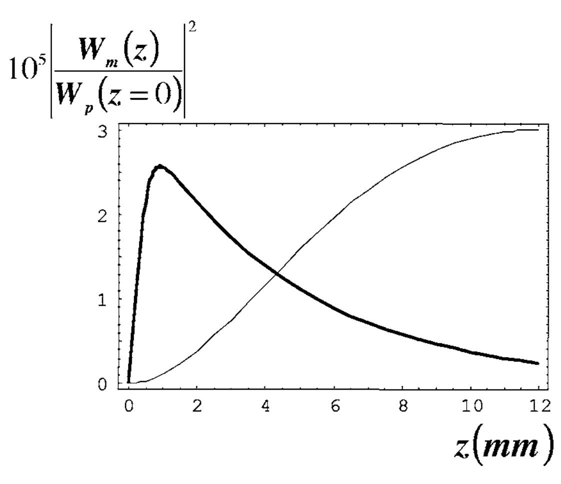

FIG. 1. Relative FWM intensity $|W_m(z)/W_p(0)|^2$ versus the atomic cell length z according to Eq. (12) in Ref. [2]. Thick and thin curves are for the situations without ($\Omega_c=0$) and with EIT ($\Omega_c=\gamma_2$), respectively. Here $W_m(z)(W_p(z))$ is the Fourier transformation of the FWM (probe) Rabi frequency. The parameters are $\kappa_{04}/\gamma_2=1$ cm^{-1} (i.e., $N\sigma_4=20$ cm^{-1}), $\kappa_{02}=40\kappa_{04}$ (i.e., $N\sigma_2=80$ cm^{-1}), $\Omega_2=4\Omega_1=0.4\gamma_2$, $\gamma_3=0.2\gamma_2$, $\gamma_1=0.001\gamma_2$, $\gamma_4=0.1\gamma_2$, $\omega=0.01\gamma_2$, $\Delta\omega_p=0$ and $\Delta\omega_j=0.04\gamma_2$ ($j=c,3,4$).

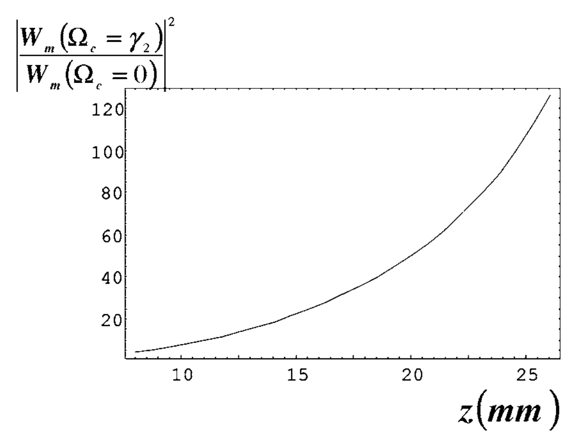

FIG. 2. Ratio of FWM intensities $|W_m(z,\Omega_c=\gamma_2)|^2/|W_m(z,\Omega_c=0)|^2$ versus the atomic cell length z. The parameters are the same as Fig. 1.

at the entrance $\Omega(z=0,t)$. The pulse shape is indispensable for such drawings [see Eq. (12) in Ref. [2]]. The pulse shape and the pulse width at the entrance are important factors in determining the FWM efficiency.

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[1] R. Buffa, S. Cavalieri, and M. V. Tognetti, Phys. Rev. A **72**, 037801 (2005).
[2] Y. Wu, J. Saldana, and Y. Zhu, Phys. Rev. A **67**, 013811 (2003).
[3] S. E. Harris, Phys. Today **50**, 36 (1997).