

## Reply to “Comment on ‘Realization of a bipolar atomic Šolc filter in the cavity-QED microlaser’ ”

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In this reply to the Comment by Bouchene *et al.* [*Phys. Rev. A* **84**, 037801 (2011)], we show that our experiment [*Phys. Rev. A* **81**, 053824 (2010)] was a legitimate demonstration of the atomic Šolc filter for the range of parameters that we have studied. The more detailed theoretical framework presented in the Comment and the interpretation of its outcome in terms of nonadiabatic jump are only necessary for larger field intensities.

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According to both the preceding Comment [1] on our work [2] and Refs. [3–5], the evolution of a two-level atom excited by a smooth-varying electromagnetic field can be well described in adiabatic bases only when  $|\partial_T \theta_n| \ll \Omega_n$  ( $T$  is the normalized time,  $\theta_n$  is the mixing angle in the adiabatic basis, and  $\Omega_n$  is the dimensionless generalized Rabi frequency). This inequality shows that nonadiabatic coupling terms should be much smaller than the magnitude of the generalized Rabi frequency or the torque vector in the Bloch vector picture. Moreover, in the limit of strong driving,  $\eta \gg |\delta|$ , which shows that the normalized Rabi frequency  $\eta$  is much larger than the normalized atom-cavity detuning  $\delta$ , a complete population transfer can occur due to a nonadiabatic jump (NAJ) at zero-crossing of a smooth-varying electric-field envelope.

We agree that the description based on the adiabatic bases and NAJ is an effective one under the strong-driving and adiabatic conditions. However, our experiment [2] was not performed under those conditions. Even the largest mean photon number (about 330) and the largest Rabi frequency in Fig. 4 of our paper still correspond to  $\eta/|\delta| \sim 1$ , which does not satisfy the strong-driving condition. In addition, the adiabatic condition was not satisfied since  $|\partial_T \theta_n|$  was comparable to  $\Omega_n$  for most of the effective interaction time as shown in Fig. 1. Therefore, the description in the adiabatic basis with NAJ is not applicable to our experiment.

It should be noted that our experiment corresponds to the two lowest-lying islands ( $m = 1$ ) in Fig. 3 of Ref. [2] and in Fig. 2(b) below, leading to the two conditions of atomic Šolc filter, namely,  $\eta = |\delta|$  and  $(\eta^2 + \delta^2)^{1/2} = m\pi$  with  $m = 1$ . On the other hand, the strong-driving condition with NAJ corresponds to a near-continuum region ( $\eta \gg |\delta|$ ) lying far above those islands in Fig. 2(a), which is an extended version (without velocity averaging for a fair comparison with Fig. 6 of Ref. [3]) of Fig. 3(d) of Ref. [2]. The same island structure and near-continuum region are also seen in Fig. 6 of Ref. [3]. It is worth noting that the locations of the maximum population not only in the island region but also in the near-continuum

region are dictated by one of the conditions of the atomic Šolc filter as shown in Fig. 2(b).

In conclusion, our experiment in Ref. [2], although done with a TEM<sub>10</sub> with a smooth-varying envelope, was not performed under the conditions where adiabatic bases with NAJ are effective. Instead, maximum population transfer occurred when the two conditions of the atomic Šolc filter were satisfied, corresponding to the successive half Rabi oscillation trajectories in Fig. 3(c) and thus to the two low-lying islands of Fig. 3(d) in our paper [2]. Therefore, our experiment is a legitimate demonstration of the atomic Šolc filter as originally reported in Ref. [2]. The adiabatic basis description and NAJ would be effective in the continuum region in Fig. 2(a). The population transfer insensitive to the field parameters in this region could be accessed under a different experimental configuration where a strong external field is injected into the cavity mode, and we plan to verify that transfer process in a future work.

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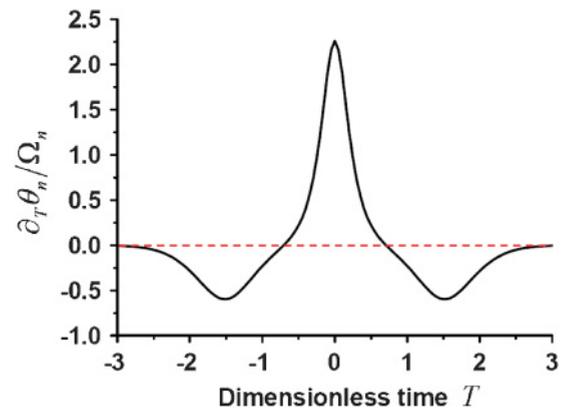


FIG. 1. (Color online) Ratio of the nonadiabatic coupling  $\partial_T \theta_n$  to the generalized Rabi frequency  $\Omega_n$  under the experimental conditions of Ref. [2]. The adiabatic condition  $|\partial_T \theta_n| \ll \Omega_n$  is not satisfied during most of the effective interaction time.

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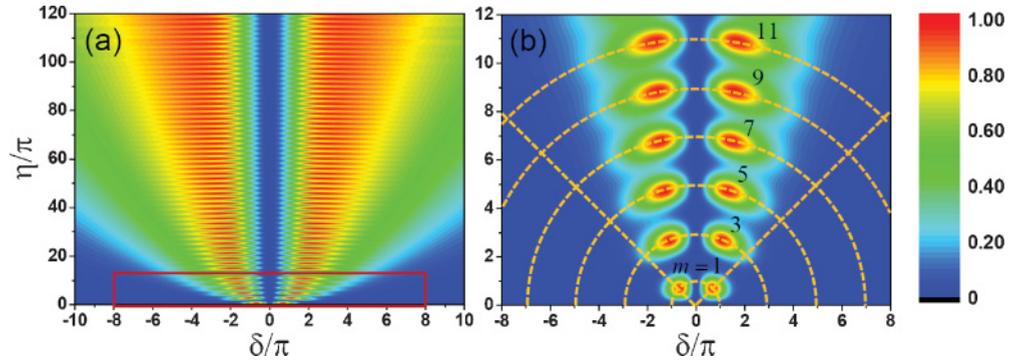


FIG. 2. (Color online) (a) Extended plot of the population transfer probability for the experimental parameters of Ref. [2]. (b) Magnified view of the region enclosed by a rectangle in (a). The adiabatic basis description and NAJ are applicable to the upper near-continuum region in (a), not to the low-lying islands as in (b). In particular, for the lowest two islands ( $m = 1$ ), the two conditions of the atomic Šolc filter are satisfied. The actual experiment corresponds to these two islands. Dotted curves indicate the condition  $\sqrt{\eta^2 + \delta^2} = m\pi$ , which is one of the atomic Šolc filter conditions.

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