Of course, the present study was not exhaustive due to the enormous number of parameters involved. The typical example of these results shown in Fig. 4 shows that the complete population inversion can not maintain for shorter pulse duration. Finally, we should note that in the results presented above the pulse area is not a parameter that should get very specific values in order to achieve complete inversion, which is quite different from the Rabi solution of the optical Bloch equations for an atomic two-level system interacting with pulsed laser fields [36].

It is worth noting that our calculation performed for typical system parameters, i.e., those of CdSe SQD and Au nanoparticle complexes, demonstrated the ultrafast exciton population dynamics induced by the few-cycle pulse train. With the development of spectroscopy technology, the single-particle spectroscopy [37–39] could probably be used to realize these effects experimentally. The interaction between SQD and MNP depends on not only the pulse parameters and interparticle distance but also the orientation of the dipole moments of the two particles, therefore, switching can be achieved not only by the traditional control via the incident electric field amplitude and interparticle distance but also the polarization of the incident pulses. We believe that the modification of the surface plasmon on ultrafast excitonic population dynamics in our proposed hybrid system will also manifest itself in other quantum interference phenomena as well, and hence our study might open up an avenue to explore and utilize the these effects and could be exploited in real SQD-MNP hybrid as high speed optical modulators and switches.

In conclusion, we have studied the phenomenon of controllable ultrafast excitonic population dynamics in the hybrid system comprised of a SQD and a metal nanoparticle by utilizing the train of chirped few-cycle pulses. We have used the effective nonlinear Bloch equations for the description of the system dynamics. We present the numerical results for the case that the system interacts with the pulse train for Gaussian or hyperbolic secant envelope. Our findings showed that the excitonic population inversion can be modified for small interparticle distances due to the interaction between exciton and surface plasmon. We also showed that the time evolution of excitonic population inversion in the SQD exhibits a steplike transition between absorption and amplifying for small interparticle distance. These results suggest a straightforward method for measuring the interparticle distances from the final state of the inversion occur. This can be realized by injecting a probe beam in order to determine the state of the SQD. Probe amplification would indicate that the SQD was left in the single-exciton state, whereas probe absorption would indicate that the SQD was left in the ground state.

Acknowledgments

We appreciate useful discussions with Y. Wu. The research is supported in part by National Natural Science Foundation of China under Grant Nos. 11374050 and 61372102, by Qing Lan project of Jiangsu, and by the Fundamental Research Funds for the Central Universities under Grant No. 2242012R30011.