Atom localization induced by interacting dark resonance

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Abstract: We propose a new simple scheme of atom localization based on the interference of double dark resonances in which the atom interacts with a classical standing-wave field and find the localization property is significantly improved.

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P.L. Knight et al. [1] used a three-level Lambda-type atom and described a related method for the sub-wavelength localization of an atom using laser induced schemes. On the other hand, the phenomenon of “dark resonances” or coherent population trapping is by now a well-known concept in optics and laser spectroscopy. M.D. Lukin, et al. [2] showed that coherent interaction leads to a splitting of dark states and the emergence of sharp spectral features and the “double-dark” resonance structure as a whole is a definite signature of a type of quantum interference effect. In our paper we use this kind of interference to study the atom localization and the localization property is significantly improved. Using the weak field approximation, we can easily get the conditional position probability is

\[ W(x) = \frac{\varepsilon^2 A^2}{[(B - \Delta x)^2 + \gamma_{ab}^2 A^2]} \]

Here \( A = \Omega_c^2 - (\Delta_0 - \Delta)(\Delta_n + \Delta_e - \Delta); \ B = (\Delta_0 + \Delta_e - \Delta)\Omega^2 \sin^2(kx) \).

Definitions of other parameters see paper [2]. Here we set the driving field as a standing field as reference [1]. Obviously by adjusting the intensity of the driving field, that is \( \Omega \), we get the different curves of position probability versus the position \( x \) shown in figures 1 and 2. From these figures, we can see that the position probability peaks just lie at the nodes of the driving standing field. Moreover, we know the periodicity of the standing wave field yields four equally probable different positions of the atom in a unit wavelength domain of the optical field when a spontaneously emitted photon is detected, so for a single required frequency measurement, the probability of finding the atom at the particular position is 1/4 [1], while here using our this scheme, the probability increases to 1/3. These new different phenomena are in essence induced by the interacting of two double dark resonances [2]. Increasing the driving field Rabi frequency (seeing figure 2), the probability peaks becomes more pronounced comparing with that in figure 1, that is to say, increasing the intensity of the driving field we can improve the spatial precision of detecting the single atom. In all, our proposed new scheme shows new advantages than other schemes (such as [1]).

Fig.1 The position probability as a function of \( kx \) with \( \Omega = 1 \).
Fig.2 The position probability as a function of \( kx \) with \( \Omega = 5 \).