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Phase sensitive coherent control excitation schemes applied to photoionization microscopy of the hydrogen atom

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Synopsis Photoionization microscopy (PM) is employed for imaging the flux of slow (meV) electrons ejected via atomic photoionization in the presence of a static electric field. Just above the ionization limit continuum and quasi-discrete states are degenerate. In hydrogen atom resonant excitation dominates over the continuum one, while the reverse holds for more complex atoms. We demonstrate theoretically that by using a bichromatic $\omega/2\omega$ laser field and by applying phase sensitive coherent control techniques it is possible to unbury and isolate otherwise obscured resonant features in PM images.

Photoionization microscopy (PM) is devoted to the measurement of the electron current probability density j in the case of photoionization of an atom in the presence of a static electric field of strength F . The spatial quantum interference structures exhibited by j are visible due to the low (meV) energy of the outgoing electrons. The PM studies are performed above the saddle point energy $E_{sp} = -2\sqrt{F}$ au. For $E_{sp} \leq E \leq 0$ quasi-bound Stark states (resonances) and continuum ones are degenerate. One of the goals of PM is to provide access to interferences stemming from the resonances which reflect intrinsic properties of the atomic system under study. In hydrogen atom the excitation of resonances is typically much stronger than the continuum one. Consequently, on-resonance PM images show specific resonant features, such as an abrupt increase of the number of fringes [1].

The Stark states of non-hydrogenic atoms are expressed as a mixture of quasi-bound and continuum hydrogenic states [2]. As a result, resonances and continua show comparable excitation strengths and the resonant image features are obscured. Here we show that, under certain conditions, it is possible to uncover the resonant signatures by applying one- and two-photon phase sensitive coherent control [3] over the excitation of the final Stark states. Then, the total excitation amplitude for each final state out of a common initial one is given by:

$$d_{tot} = E_{2\omega} \exp(i\varphi_{2\omega}) D^{(1)} + E_{\omega}^2 \exp(i2\varphi_{\omega}) D^{(2)},$$

with $E_{2\omega}/\varphi_{2\omega}$ and $E_{\omega}/\varphi_{\omega}$ being the laser field amplitudes/phases and $D^{(1)}$ and $D^{(2)}$ one and two-photon excitation dipole matrix elements, respectively. Figure 1 shows the results of a theoretical hydrogenic calculation.

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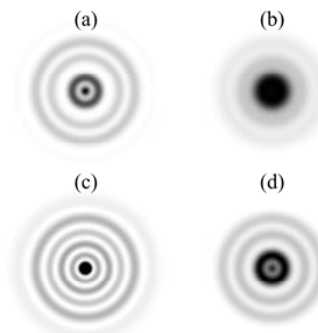


Figure 1. Hydrogenic PM images for ground state excitation and for $F=680$ V/cm and $E/|E_{sp}|=-0.8943$ (i.e. on the red size of the ($n_1=5$, $m=0$) shape resonance). (a) Single-photon (2ω) excitation only, (b) Two-photon (ω) excitation only, (c) Bichromatic $\omega/2\omega$ excitation, $\Delta\varphi = \varphi_{2\omega} - 2\varphi_{\omega} = 0$ and laser intensities optimized for bringing out the details of the resonance, (d) Same as in (c) but with $\Delta\varphi = \pi$.

With either the ω or the 2ω laser field alone the images fail to exhibit the five dark fringes of a weak resonance. This is achieved solely by applying both fields, setting the appropriate difference $\Delta\varphi = \varphi_{2\omega} - 2\varphi_{\omega}$ (here $\Delta\varphi = 0$) and choosing appropriate values for $E_{2\omega}$ and E_{ω} . It turns out that the method appears to be quite efficient and the continuum excitation can be efficiently suppressed when the number of continua is small, i.e. just above E_{sp} .

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