Title	Coherent Time Evolution of Highly Excited Rydberg States in Pulsed Electric Field: Opening a New Scheme for Stringently Selective Field Ionization (NUCLEAR SCIENCE RESEARCH FACILITY-Beams and Fundamental Reaction)
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Coherent Time Evolution of Highly Excited Rydberg States in Pulsed Electric Field: Opening a New Scheme for Stringently Selective Field Ionization

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Coherent time evolution of highly excited Rydberg states in Rb ($98 \leq n \leq 150$) under pulsed electric field in high slew rate regime was investigated with the field ionization detection. We observed for the first time a discrete transition of the threshold ionization field with slew rate, the behavior of which depends also on the position of the low l states relative to the adjacent manifold. The experimental results strongly suggest that the coherent interference effect plays decisive role for such transitional behavior, and bring us a new, quite effective scheme for the stringently selective field ionization.

Keywords : Rydberg atoms/selective field ionization/pulsed electric field/dark-matter axion search

Highly excited Rydberg states in the ramped electric field is one of the most interesting system for investigating the coherence effects in the time evolution of a quantum systems[1]. With increasing principal quantum number *n,* more numbers of the Rydberg Stark states are coherently excited along the increasing electric field, thus the coherence effects becoming more and more important factors to the behavior of the Rydberg states[2]. In spite of this promising feature and also of their potential applicability to the wide area of fundamental physics research including cavity QED and quantum computations, the Rydberg states with high $n > 80$ have not been investigated in detail, partly because of the difficulty in selectively detecting a particular state from many close-lying states[2].

We here investigated the time evolution of highly excited Rydberg states in Rb ($98 \leq n \leq 150$) under pulsed electric field in high slew rate regime[3]. Thermal atomic beam of Rb is introduced into the laser interaction region where the Rb atoms are excited to a highly excited Rydberg state via the two-step laser excitation process from the ground $5s_{1/2}$ state through the second excited $5p_{3/2}$ state. The excited Rydberg state is then fed to the field ionization region, 40 mm apart from the laser interaction region, and ionized with a pulsed electric field in high slew rate regime. The resulting electrons liberated with the field ionization process are detected with a channel electron multiplier. All the data acquisi-

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Scope of research

Atoms, nuclei, and dark matter particles in the Universe are studied with quantum electronic methods: Current research subjects are 1) search for a cosmological dark-matter candidate particle, axion, in the Universe with the Rydberg-atom cavity detector, 2) highly excited Rydberg atoms in an electric field and their applications to fundamental physics research, and 3) nuclear magnetism in 3-5 semiconductors with laser-assisted Overhauser process and optical pumping.

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tion and analyses were performed on-line as well as off-line with a LabVIEW DAQ system.

In Fig. 1 shown is typical field ionization spectra of 111*s*,111*p*, and 109*d* states: The upper part shows the originally obtained raw spectra, while the lower part represents the resulting spectra by taking derivative of the above raw spectra. Fig. 2 shows the comparison of the spectral change of the *s* and *p* states with varying slew rate, where the spectra of these states taken independently were superimposed to each other. These spectra show clearly that the field ionization for both the *s* and *p* states has a single threshold, which does not vary continuously but change discretely with the slew rate applied. Note also that this slew rate dependence is quite different for the *s* and *p* states: For example, the *s* state threshold value is 5.2 V/cm at the slew rate of 11 V/(cm μs), while that of the *p* state is 1.7 V/cm, almost 200% difference. This is to be compared to the case of the purely adiabatic transition process at which the expected difference is only 5 %.

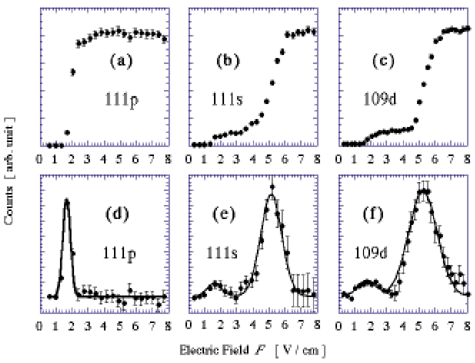

Figure 1. Typical field ionization spectra of *s*, *p* and *d* states.

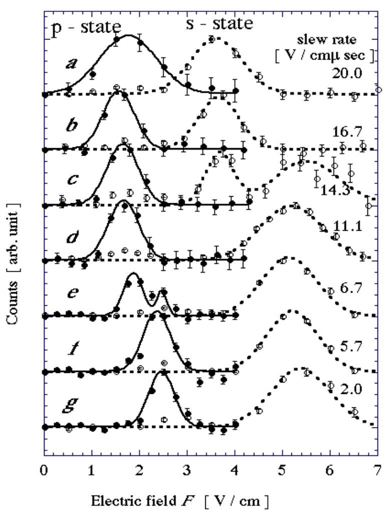

Figure 2. Slew rate dependence of the field ionization threshold for the 111*s* and 111*p* states.

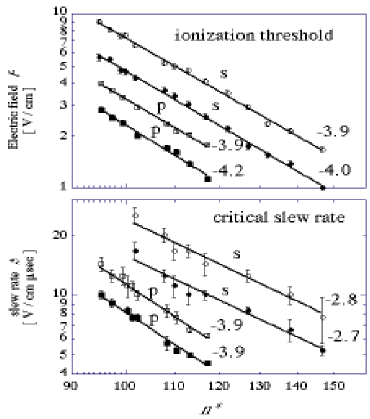

Figure 3. Dependence of the field ionization threshold values and the slew rate on the principal quantum number *n**.

This transitional behavior observed for the first time here has also quite regular *n* dependence as shown in Fig. 3 where the threshold field and the corresponding slew rate are plotted as a function of the effective principal quantum number *n**. This regular dependence thus indicates that the transitional behavior is quite general and strongly suggests that the coherent interference effects in the time evolution play the decisive role to the field ionization processes. Also the experimental results show that the transitional behavior of the low *l* states depends on the position relative to the adjacent manifold and the stringently selective ionization are applicable for a wide range of highly excited Rydberg states, thus opening a quite effective way to utilize such highly excited Rydberg states for the investigations of and applications to fundamental physics research. One of the interesting application for such selective field ionization is a realization of ultra low noise microwave detector in which a single microwave photon is detected one by one with the Rydberg atoms in a well cooled cavity: This is one of the underlying aim of the present study and such a detector was developed and is being utilized to search for dark matter axions in our galactic halo[4].

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