Nuclear Instruments and Methods in Physics Research B 337 (2014) 39–44

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

A cold target recoil-ion momentum spectroscopy for the investigation on the dynamics of atomic and molecular reactions in Shanghai

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ARTICLE INFO

Article history:
Received 26 June 2014
Received in revised form 22 July 2014
Accepted 23 July 2014
Available online 12 August 2014

Keywords:
Cold target recoil-ion momentum spectroscopy
Time of flight
Pulsed electron gun
Resolution of momentum
Kinetic energy release

ABSTRACT

A cold target recoil-ion momentum spectroscopy to study the fragmentation of molecules impact by electrons has been described, which mainly comprises a pulsed electron gun, a supersonic gas jet, a time-of-flight (TOF) spectrometer, a multi-hit position sensitive detector and a data acquisition system. According to the measured TOF data and corresponding positions information on the detector, the recoil-ions' trajectories can be reconstructed and their initial 3D momentum vectors can be calculated. The energy spread of the electron gun, about 8.5 eV, and the resolution of momentum component parallel and perpendicular to the TOF direction for recoil-ions, about 0.23 and 0.35 a.u., respectively, are obtained by using helium as the gas target. To test the performance of the setup, the fragmentation of nitrogen induced by 100 eV electrons impact is investigated and some reaction channels with different kinetic energy distributions, like dissociative ionization and Coulomb explosion, are analyzed. Good agreement is achieved with previous studies.

1. Introduction

Cold target recoil-ion momentum spectroscopy (COLTRIMS), has been developed for more than twenty years, this rapidly developing technique provides an efficient and precise experimental tool to study various of atomic and molecular reactions [1–3]. The first system was built in Frankfurt University by Ullrich and Schmidt-Böcking in 1987 [4]. Recently COLTRIMS has become a standard experimental device for studying atomic and molecular many-particle reactions [5–13].

The advantage of the COLTRIMS is that it allows measuring the time of flight, and the impact position on the detector of the all fragments produced in the collision, from which the collision process can be reconstructed [10,14]. After the collision process, the charged particles are extracted by an electric field, through a field free drift tube and finally detected with a time and position sensitive detector. The TOF acts as a mass spectrometer which can be used to determine the mass and charge state of the recoil-ion, and three dimensional momentum vectors can be deduced for both electrons and recoil ions. Therefore kinematically complete experiment can be achieved and fully differential cross sections can be extracted. For example, by measuring the ejected electron and the recoil-ion in coincidence, Schulz and his colleagues obtained three-dimensional images of the complete electron pattern for the single ionization of helium by the impact of C^{6+} ions with energy of 100 MeV/a.m.u. [7]. The collection solid angle, in most cases, is close to 4π for both ions and electrons.

In this paper, we report a new COLTRIMS in Shanghai for studying the interaction between low energy electrons and molecules with a pulsed/static transverse extraction field. The energy of the incident electron beam is ranging from a few eV to 2 keV.

2. Device setup

2.1. Overview of the experimental setup

Fig. 1 shows the main features of the experimental arrangement in a schematic way. An essential part of the experiment is the pulsed electron beam. This is produced by an electron gun and provides beams in the energy range from a few up to 2000 eV. The electron beam is crossed with a beam of atoms or molecules provided by a supersonic gas jet. This jet is generated by injecting high pressure (2 bar) gas into the vacuum chamber through a 10 μm nozzle operating at room temperature. About 10 mm (variable) downstream of the nozzle, a skimmer of 0.1 mm diameter is used

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http://dx.doi.org/10.1016/j.nimb.2014.07.023
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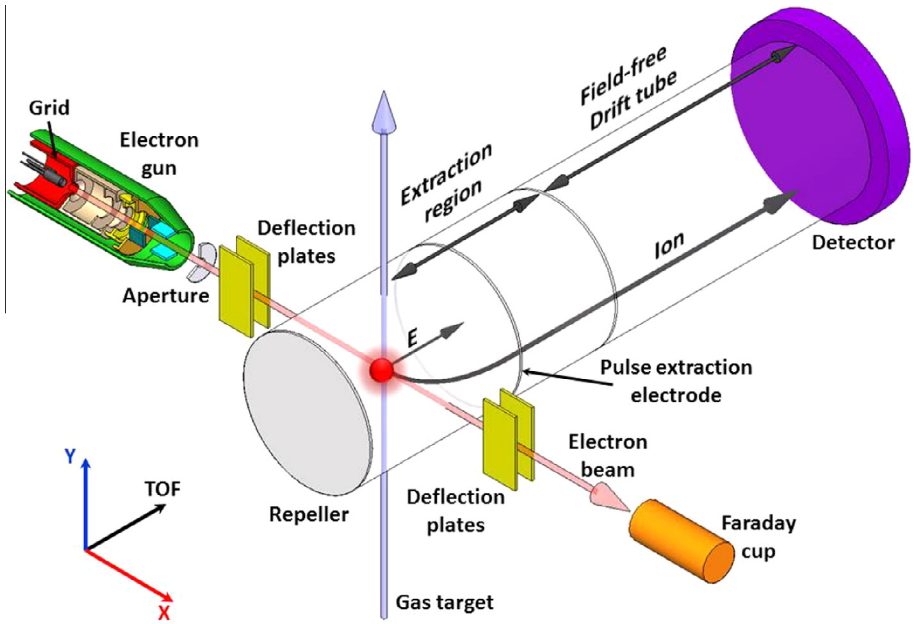

Fig. 1. Schematic diagram of the COLTRIMS in Shanghai.

to obtain a gas beam with a well-defined geometry. The final diameter of the gas jet interacting with the electron beam is around 2 mm. High vacuum in the collision chamber is maintained using a multistage pumping system. The background vacuum in the collision chamber, during an experiment, is better than 2×10^{-10} Torr. The collision chamber itself is made from commercially available pure Titanium. This is because, despite its toughness compared to Stainless Steel, Titanium has very good properties regarding eliminating effects from magnetic permeability and ultra high vacuum operation. Finally a pair of coils was used to cancel out the earth's magnetic field.

The recoil-ions formed in the interaction region are extracted by an electric field E. The ions are accelerated in the extraction region and then enter the field-free drift tube section. Finally they hit a 75 mm diameter multi-channel-plate (MCP) detector [13]. The MCP is equipped with delay-line anode readout and has multi-hit capability, the detector is both position and time sensitive. To reduce the uncertainty due to the finite target size in the time of flight direction, the TOF spectrometer adopts a time-focusing geometry, i.e., the length of the field-free drift tube (20 cm) is twice that of the extraction region (10 cm) [15]. Based on the TOF and corresponding position data recorded by the MCP detector, a reconstruction of the 3D momentum vectors for each recoil-ion can be constructed.

The electric field used for extracting the ions, along the TOF direction, can be either pulsed or static. One advantage of using a pulsed field is that does not affect the incident electron beam, thus a stronger extraction field can be employed to get higher collection efficiency [13]. It consists of two parts, a repeller and a pulsed electrode (1.2 cm away from the collision region) to generate the pulsed extraction field and a static field region (8.8 cm in length) close to the drift tube (see Fig. 1). After the incident electrons have passed through the collision region, the pulsed extraction field is switched on with a rise time of about 20 ns. It is clear that the changing field will blur the time of flight measurement. This is one disadvantaged of using a pulsed extraction field. The defect can of course be eliminated by using a static extraction field, however in this case the incident electron beam will be deflected. Hence, to steer the incident electron beam, deflection plates should be used. Typically, a pulsed extraction field of $E \sim 25$ V/cm is used for collecting molecular ions, however a weaker static extraction field $E \leqslant 5$ V/cm is applied for more accurate measurements.

A pre-requisite for obtaining good resolution in fragmentation experiments is a fast electronic and high performance data acquisition (DAQ) system. This system collects information from the detectors, combines the data into complete events and writes to a file which stores the experimental results for offline analysis. In the present COLTRIMS, a VME64x system is utilized for data acquisition. The main module is a TDC V1290N that houses 16 independent multi-hit/multi-event TDC channels developed by CAEN [16]. The unit consists of two 21 bit HP-TDC (High Performance TDC) chips, with 25 ps LSB (Least Significant Bit), 52 μs full scale range and 5 ns double hit resolution. Multi-coincidence measurement were performed in event mode and all data were recorded in list mode by a 6U VME bus embedded computer VP919 [17].

2.2. The pulsed electron beam

COLTRIMS comes to optimum use in the experiments discussed here when a narrow pulse width (of the order of ns or even shorter) monoenergetic electron beam is used. The TOF measurement depends on the pulse width. Thus the momentum resolution in this TOF direction is limited by the pulse width in this configuration. For example in Ref. [18], an electron beam width of 1.5 ns was used, which is close to the lower limit of the pulse width for thermo-cathode guns. In some electron guns a photocathode is used to generate electron beams with a very short pulse width, e.g., 500 ps at 100 eV [19]. But the lifetime of the photocathodes is not that long and such guns usually have structural complexity, so the traditional thermo-cathodes are still widely used.

The gun in this work, based in a thermo-cathode too, was designed to emit electron beams with energy from a few up to approximately 2000 eV [20]. A grid between the anode and the cathode in the electron gun provides the first control of the beam and can be used to shut down the beam if needed (shown in Fig. 1). To obtain a pulsed beam the grid voltage is set negative with respect to the cathode, this will suppress the emission of the electrons. Then, an ultrafast pulse voltage can be applied to the grid via a separate pulse junction box to extract the pulsed electron