# A Bragg curve detector and its application in AMS measurements for medium-weight nuclides

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**Abstract** The schematic layout and principle of a Bragg curve detector were showed in this paper. A Bragg curve detector was systemically modified and its performance was improved. The total energy resolution of the detector is 0.9% for alpha particle at energy of 5.48 MeV from $^{241}$Am source, and the Bragg Peak resolution is 1.6%. Measurement of medium-weight nuclides by using the Bragg curve detector were carried at CIAE-AMS system. series of $^{36}$Cl and $^{41}$Ca standard samples were measured. The results showed that this Bragg curve detector could clearly identify isobars $^{36}$Cl-$^{36}$S and $^{41}$Ca-$^{41}$K. The results also showed that the $\Delta Z/Z$ of 1/47, corresponding to Bragg Peak resolution is 2.1% at ion atomic number of about 16. The Bragg curve detector can be successfully used for AMS measurement.

**Key words** Bragg curve detector, isobaric identification, AMS, $^{36}$Cl, $^{41}$Ca

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## 1 Introduction

Due to the isobar interference, the sensitivity is restricted in AMS measurement[1—3] for medium-weight nuclides. Improving the isobar identification power is the key point for AMS measurement. Measurement of medium-weight nuclides by AMS needs a high-performance detector which can effectively improve the isobar identification.

A Bragg curve detector (BCD)[4] could obtain various information of incident ion through stopping power curve (Bragg curve). So, the Bragg curve detector is continuously used and developed in the world. The energy resolution for a Bragg curve detector made by XIE Yuan-Xiang[5] was 1.5% and 2.6% for alpha particle at energy of 8.78 MeV and 6.02 MeV respectively, and the resolution of Bragg peak was 2.7%. Another Bragg curve detector was developed by ZHENG Zhi-Hao[6], its energy resolution was 0.9% for alpha particles at energy of 5.48 MeV. This Bragg curve detector was used for elasticity recoil detect technique (ERDA)[7], the results shown that it is nearly linear relationship between atomic number and Bragg peak amplitude. Bragg curve detector used for AMS measurement was reported by Santos[8] and its results showed that Bragg curve detector has a higher performance of charge identification especially for medium-weight nuclides measurements at lower energy.

The schematic layout and principle of our developed Bragg curve detector was described. Application in AMS measurements for medium- weight nuclides at China Institute of Atomic Energy (CIAE) was reported in this paper.

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## 2 Performance of our BCD

### 2.1 Principle and structure

As an energetic charged particle passes through a Bragg curve detector, it loses energy along the path (so-called Bragg curve). At ion energy of under 1 MeV/amu, the energy loss $\mathrm{d}E/\mathrm{d}x$ reaches its maximum. The maximum energy loss is called Bragg peak. The amplitude of this peak, which is independent of the energy and mass, is found to be directly proportional to the nuclear charge of particle. Particles of same Z would have same amplitude of Bragg peak, even if they have a different energy and ranges in a Bragg curve detector. If the collected charge is $\Delta Q$ in an interval time of $\Delta t$, the current signal of anode is given by following formula:

$$i=\frac{\Delta Q}{\Delta t}=\frac{\Delta Q}{\Delta x}\frac{\Delta x}{\Delta t}=\frac{\Delta Q}{\Delta x}V_{\mathrm{D}}\propto\frac{\Delta E}{\Delta x}V_{\mathrm{D}}.$$

Where $V_{\mathrm{D}}$ is the drifting velocity of electrons in gas, it is a constant in a given reduced field. The average ionization energy in a certain gas is also a constant, thus $\Delta Q\propto\Delta E$. Electrons at the end of Bragg curve are firstly collected, thus the current signal of anode is actually a mirror of the Bragg curve.

The current signal of the detector is read out by a charge-sensitive preamplifier followed by several shaping spectroscopy amplifiers in parallel with different shaping time constants.

The spectroscopy amplifier with a short shaping time constant (about 0.5 μs) gives an output signal, the amplitude of the signal is corresponds to the area under the Bragg peak. The spectroscopy amplifier with a shaping time constant (about 6 μs) longer than the collecting time of electrons gives an output signal of the total energy. The spectroscopy amplifier with a shaping time constant between 6 μs and 0.5 μs give output signals of delta energy signal. According to this principle, a Bragg curve detector was built for AMS measurement by CIAE-AMS group and its performance was tested[9].

### 2.2 Improvement of the BCD

#### 2.2.1 Improvement

The performance of a detector depends on its physical design and mechanical configuration. The important components for a Bragg curve detector are entrance window, cathode, grid and anode. All of those can affect the performance of a Bragg curve detector. A fine entrance window with good film uniformity must be as thin as possible to reduce the energy straggling and angle scatter. Well designed cathode and grid would have better efficiency to avoid produced electron screening and increase the homogeneity of electric field. Adjusting the distance between grid and anode can increase the ability of the detector at lower energy and thus improve the detector limitation. The pressure of working gas is also a factor of influence for energy resolution. The resolution of CIAE-AMS Bragg curve detector was improved by modifying these designs of these components.

#### 2.2.2 The performance of the BCD

In order to get good performance of the detector, modifications of the detector have been done concretely. The modifications include the following the factors: redesign the cathode and grid mesh; modify the anode electronic loop, adjusting the cathode-grid reduced field and grid-anode reduced field, choosing the suitable gas and pressure, choosing appropriate preamplifier.

A schematic layout of the CIAE-AMS Bragg curve detector (CIAE-AMS BCD) is shown in Fig. 1.

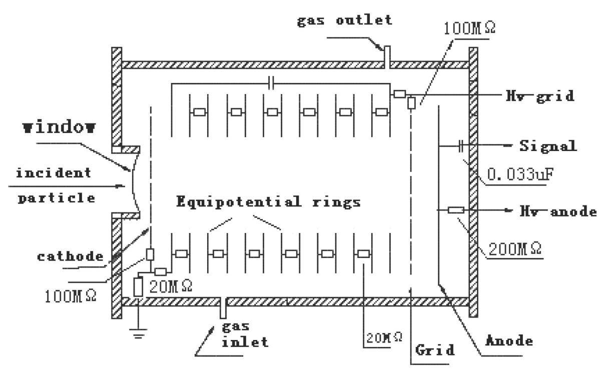


Fig. 1. Schematic layout of CIAE-AMS Bragg curve detector.

The primary design parameters of the CIAE-AMS Bragg curve detector are summarized in Table 1.

After series modification and test, the best working conditions for CIAE-AMS Bragg curve detector are obtained. Cathode-grid reduced filed is 0.26 V/cm·Torr, and grid-anode reduced filed is 1.94 V/cm·Torr in P10 gas. The anode signal was fed to a sensitive-charge preamplifier of ORTEC 142IH and Shaping Amplifier of ORTEC 672.

In a P10 gas of 170.8 mbar, the resolution of the detector was 0.9% for alpha particle at 5.48 MeV from a $^{241}$Am source, and the Bragg peak signal resolution was 1.6% under the best working conditions.

Table 1. Parameters of the CIAE-AMS Bragg curve detector.

| | |
|---|---|
| cathode to grid distance | 250 mm |
| grid to anode distance | adjustable |
| grid wire diameter | 50 μm |
| grid spacing | 1 mm |
| window thickness | 1.5 μm(Mylar) |
| window supporting | 7 mm×1 mm |
| grid efficiency | 97.5% |
| equipotent rings spacing | 19 mm |
| resistor chain | 20 MΩ×13 |
| cathode and anode diameter | $\Phi$153 mm |

## 3 Applications in AMS measurement

For developing a perfect method of Bragg curve detector in AMS technology, applications biased on Bragg curve detector in AMS measurements for medium-weight nuclides were carried out. A series of medium-weight nuclear standard samples were measured at China institute of Atomic Energy (CIAE) AMS Bean Line.

### 3.1 Isobaric identification for $^{36}$Cl and $^{36}$S

$^{36}$Cl is often used to determine erosion rate and geological age. However, ratio of $^{36}$Cl/Cl in natural sample is very low and it can be only measured by AMS. The main interfere in AMS measurement is its isobar $^{36}$S. Effective identification of $^{36}$S from $^{36}$Cl by a detector is an optimal approach to improve the sensitivity of AMS measurement for $^{36}$Cl.

In the measurement of $^{36}$Cl standard sample by AMS, $^{36}$Cl$^{-}$ was extracted from the AMS ion source. Terminal voltage of HI-13 Tandem Accelerator is set to 8.2 MV. Selected by magnetic analyzer and electrostatic analyzer, $^{36}$Cl$^{8+}$ and $^{36}$S$^{8+}$ with an energy of 73.9 MeV were obtained and entered into the CIAE-AMS Bragg curve detector. The resolution of total energy is 1.2% and the Bragg peak resolution was 2.1%. The Bragg peak signal spectra are showed in Fig. 2(a). The residual energy ($E_{\rm r}$) signal spectra are showed in Fig. 2(b). The two-dimension spectra of Bragg peak versus $E_{\rm r}$ was showed in Fig. 2(c). As showed in Fig. 2, the detector can identify $^{36}$Cl from its isobar $^{36}$S clearly.

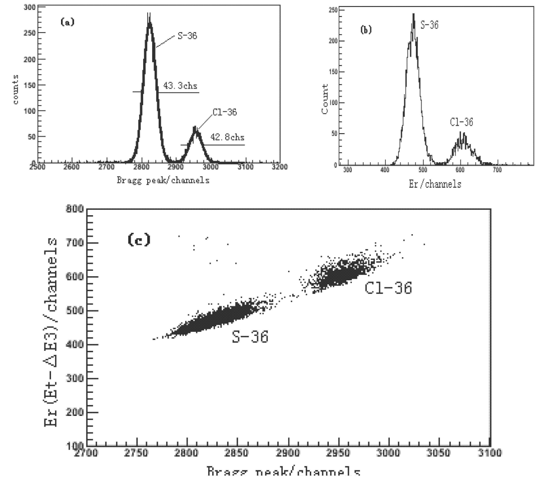


Fig. 2. (a) Spectra of the Bragg peak for measurement of $^{36}$Cl standard sample; (b) Spectra of $E_{\rm r}$ for $^{36}$Cl standard sample; (c) Two-dimension spectra of Bragg peak versus $E_{\rm r}$.

The $S$ is an important factor for estimating the identifying ability of a detector.

$$S=\{E_{\rm B}(^{36}{\rm Cl})-E_{\rm B}(^{36}{\rm S})\}/\Delta E({\rm FWHM}).$$

The $S$ factor of Bragg peak and $E_{\rm r}$ signal were 3.1 and 2.9, respectively.

In the measurement of nuclides with Z of about 16, a $\Delta Z/Z$ of 1/47 was achieved, corresponding to Bragg peak resolution of 2.1%. Compared with a $\Delta E$-$E$ detector, this Bragg curve detector had a higher charge identification capability, and could directly give the $Z$ value within 1.2% uncertainty according to the relationship between Bragg peak and atomic number of nuclide.

### 3.2 Isobaric identification for $^{41}$Ca and $^{41}$K

Calcium isotope trace analysis experiment is very important for the application on study of bones as well as calcium depositing and exchanging in the human body. In recent years, trace analysis experiments of long-lived radionuclide of $^{41}$Ca had become more important application of AMS in biomedicine field. The advantage of $^{41}$Ca tracer is lower radiation damage and they could be used for longer-time tracer in body. Whereas, $^{41}$Ca tracer experiments requires that AMS measurement has a higher sensitivity. Identification of $^{41}$Ca from its isobar $^{41}$K could improve measurement sensitivity in AMS measurement.

$^{41}$Ca$^{-}$ was extracted from the AMS ion source. Terminal voltage of HI-13 tandem accelerator is set to 8.2MV. Charge-state +8 was selected by magnetic analyzer and electrostatic analyzer. $^{41}Ca^{8+}$ and its isobar $^{41}K^{8+}$ with an energy of 87.8 MeV were obtained and entered into the CIAE-AMS Bragg curve detector. The total energy resolution of CIAE-AMS Bragg curve detector was 1.6% and the Bragg peak resolution was 3.2%. The two-dimension spectra of total energy $E_t$ versus residual energy $E_r$ is showed in Fig. 3. This test showed that the Bragg curve detector could also clearly identified $^{41}Ca$-$^{41}K$. The $S$ factor of Bragg peak and $E_r$ signal were 1.6 and 1.9, respectively.

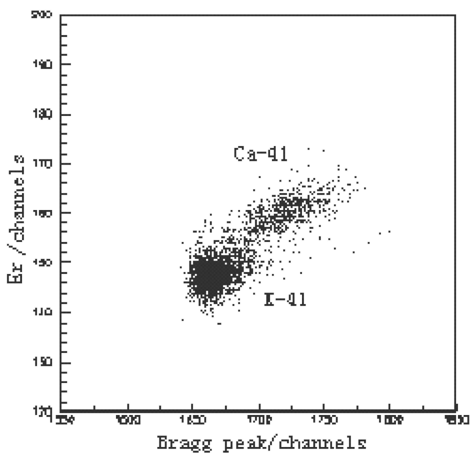


Fig. 3. Two-dimension spectra of Bragg peak versus $E_r$ of 41Ca standard sample.

## 4 Conclusions and discussion

A Bragg curve detector was systemically modified and its performance was improved. The total energy resolution of the detector is 0.9% for alpha particle at 5.48 MeV from a $^{241}Am$ source, and the Bragg peak signal resolution is 1.6%. Compared with same type detectors used in the world, this detector has a good performance and is successfully used to measure medium-weight nuclides in AMS. Series of $^{36}Cl$ and $^{41}Ca$ standard samples were measured. The detector could clearly identify $^{36}Cl$-$^{36}S$ and $^{41}Ca$-$^{41}K$. The results showed that the Bragg curve detector could be successfully used for AMS measurement.

In the measurement of nuclides with $Z$ of about 16, a $\Delta Z/Z$ of 1/47 was achieved, corresponding to Bragg peak resolution of 2.1%. Compared with a $\Delta E$-$E$ detector, this Bragg curve detector had a higher charge identification capability.

By using the waveform recognition technique, the performances of Bragg curve detectors could be further improved in terms of charge identification, especially for medium-weight nuclides measurements by AMS. This work will be done in the future.

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