High dynamic range ion imaging using individual pixel reset of SCAPS detector

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1. Introduction

Stigmatic SIMS with magnetic sector has a potential to achieve high duty ratio isotope imaging using high intensity beam due to the probe size-independent spatial resolution of stigmatic ion optics and continuous mass separation with magnetic prism. Stacked CMOS active pixel sensor (SCAPS) is a two-dimensional ion detector consisting of 576 × 600 pixels, capable of direct detection up to 5×10^4 ions per pixel [1] and single ion detection using a multiple sampling method [2].

The combination of stigmatic SIMS and SCAPS has enabled precise isotope imaging on the microscale [3] and continues to yield new insights [e.g., 4]. In this study, we developed a high dynamic range (HDR) ion imaging system by devising a readout method to maximize the advantages of direct isotope imaging.

2. Individual pixel reset readout

Ion signals generated by the interaction of incident ions with the pixel electrodes are stored as charge in the capacitor of the pixel. The capacitor is connected to the gate of the readout circuit and the source of the reset circuit, allowing non-destructive readout to read out signals without changing the charge (NDRO) and prevent saturation by setting the capacitors to reset voltage (DRO).

Although DRO contains switching noise of the reset transistor, resetting the capacitor after readout allows the pixel to continue detecting intense signals without saturation. The X-Y addressing system can assign pixels where low-signal pixels continue to integrate with NDRO and high-signal pixels operate with DRO.

3. Experimental conditions

A stigmatic SIMS instrument (CAMECA, ims-1270e7) at Hokkaido University generated $^{24}Mg^+$ ion image using 23keV O^- beam of 40 nA irradiated over 100μm on a polished thin section of NWA5966 meteorite containing spinel ($MgAl_2O_4$), anorthite ($CaAl_2Si_2O_8$) and melilite ($Ca_2MgSi_2O_7$-$Ca_2Al(Si,Al)_2O_7$).

Ion images were acquired at a readout rate of 5.25 seconds per frame. The driving pulses were generated by an FPGA programmed with LabVIEW software to select the reset pixels that exceeded the threshold value from the previously acquired $^{24}Mg^+$ image. Pixels to be reset were connected to the reset voltage for 12.5μsec after readout.

4. High dynamic range (HDR) ion imaging

Figure (a) shows a $^{24}Mg^+$ image for single frame in linear color scale containing micron-sized spinel (sp), anorthite (an) and melilite (mel) grains. The pixels exceeding 0.01 volts in the image were selected as pixels to be reset, and 1000 frames were continuously acquired.

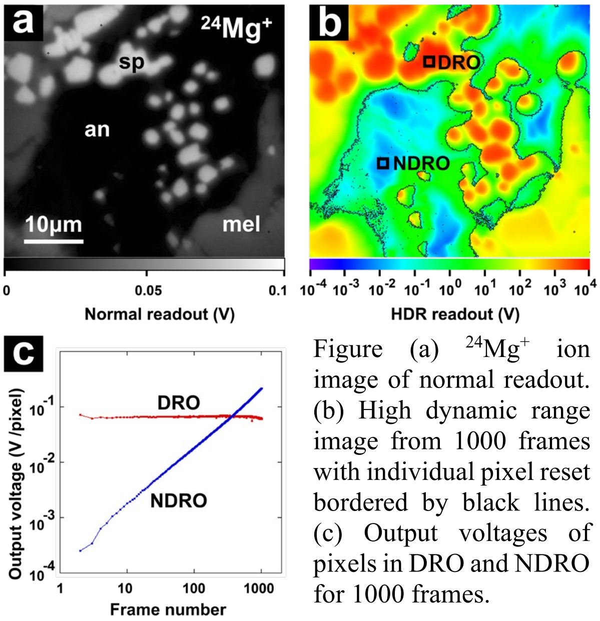

Figure (a) $^{24}Mg^+$ ion image of normal readout. (b) High dynamic range image from 1000 frames with individual pixel reset bordered by black lines. (c) Output voltages of pixels in DRO and NDRO for 1000 frames.

Figure (b) is a composite HDR image of NDRO and DRO pixels. The output voltages of DRO pixels were averaged and multiplied by the number of frames. The color range is 8 orders of magnitude. The concentration differences in this region were found to be six orders.

The intensities over 1000 frames are plotted in Figure (c) from pixels operated with NDRO and DRO, indicated by the squares in Figure (b). The NDRO shows a linear accumulation and the DRO is nearly constant, indicating that the HDR system can provide statistically beneficial information over the entire intensity range.

5. Summary

The newly developed HDR ion imaging system has demonstrated the ability to continuously acquire ion intensity distributions over six orders of magnitude within the same field of view. This system realizes precise imaging dating using radionuclides and hydrogen isotope ratio imaging of anhydrous and hydrous mineral mixtures.

References

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