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Noise analysis of SCAPS-II ion imager

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A solid-state ion imager SCAPS has been proposed and demonstrated two-dimensional isotope ratio imaging with permil precision coupled with a stigmatic SIMS. The SCAPS system can measure high ion flux with an accuracy of the statistical error. However, the readout speed currently optimized at 0.05 frames/s is not sufficient for the time-critical applications. In order to realize real-time readout without loss of quantitative capability, high sensitivity is needed to overcome the read noise. The output signal fluctuation from SCAPS caused by 1 incident ion (i.e., conversion gain) was 30 micro V/ion pixel, whereas the read noise was 85 micro V. We evaluated newly designed ion imager SCAPS-II with higher conversion gain and noise reduction mechanism to achieve high-sensitivity corresponding to real-time readout.

The SCAPS-II has 504x504 pixel 7 x 7 micron in size with 65% fill factor. Improvement of the conversion gain can be achieved to reduce the pixel capacitance according to the relationship of Q = CV where Q is the accumulated charge, C is the capacitance, V is the output voltage. The pixel capacitance of SCAPS-II is designed to 3.5fF, which is 4 times smaller than SCAPS (14fF). In order to increase dynamic range on the image detection, the conditional reset function was incorporated.

We also incorporated noise-reducing mechanism by multiple signal sampling using a switched capacitor (SC) integrator. The analog signal of pixel is sampled for multiple times as a difference voltage between pixel signal and a reference voltage via capacitor. The voltage is integrated in analog memory consisting of an amplifier with a feedback capacitor. The multiple sampling circuits are installed into each column totally 504 units and sample the signal of pixels in a row containing 504 pixels selected by a row selection pulse at the same time. This function realizes 16 times sampling for one pixel signal at 10 frames/s and 12.5 frames/s with 1 time sampling. The 2-line analog buffer output the integrated signal to read faster twice.

The conversion gain for ion was evaluated using a SIMS instruments (Cameca ims-1270). The imager is installed in a vacuum chamber and cooled at 173K to achieve long integration time by reducing thermally generated dark current. In order to decrease the noises including fixed pattern noise, nondestructive readout correlated double sampling is used to subtract a dark frame from a signal frame obtained without pixel reset. The incident ion number is counted by Faraday cup attached to the SIMS instrument. The saturation level of signal is about 5x10e3 ions/pixel. The noise is increasing statistically until the noise floor becomes dominant. The conversion gain of SCAPS-II was estimated to be 150 micro V/ion, which is 5 times larger than SCAPS. The noise using multiple-sampling method is not decrease along the slope-1/2 line. In order to investigate the noise source, the different sampling sequence called frame-averaging method is applied. The frame averaging sequence samples the pixels signal once every frame rates and averaging the frames while the multiple-sampling method samples multiple times in tens of micro sec order. The frame-averaging method takes long time for sampling but the noise reduction efficiency is higher than multiple-sampling method under 50 micro V. However the noise source is not clarified yet, the possible noise source is the 1/f noise of the MOS transistor because the difference between multiple-sampling method and frame-averaging method is the required time in sampling.

The capability of single ion detection is evaluated with the combination of multiple-sampling method and frame-averaging method. The frame ratio is 3.5 frames/s, therefore, it takes 14.4 seconds to obtain the ion image. The histogram of imager output of ion incident region shows the peak around 150 micro V. Considering the conversion gain of 150 micro V/ion, this peak indicates single ion signal.