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# Superconducting Strip Ion Detectors for Time-of-flight Mass Spectrometer

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**Abstract**

Superconducting detectors are promising as ion detectors for time-of-flight mass spectrometers (TOF MS). They can achieve mass-independent detection efficiency even for macromolecular bombardments, because output signals are produced through the deposited kinetic energy at ion impact instead of secondary electron emission that is the ion detection mechanism of conventional microchannel plate (MCP) detectors or secondary electron multipliers (SEM). Among the superconducting detectors, the superconducting strip ion detectors (SSIDs), which consist of several hundreds of superconducting lines with a width of a few hundreds nm and a thickness of a few tens of nm, have a fast response time of less than 1 ns. Inherently, the response time of SSIDs is determined by kinetic inductance, so that it was difficult to realize a fast SSID with a large detection area. However, we succeeded in realizing the detector size up to 5×5 mm$^2$ without response time degradation by using a parallel configuration.

*Keywords* : TOF MS, biomolecule, stripline, SSID

## I. Introduction

Superconducting strip detectors can achieve the sub-ns fast response time with high detection efficiency [1, 2]. Accordingly, the detectors are expected as a key device component for the optical communication or the quantum cryptography [3-8]. In that infrared photon detection, it may be called as a superconducting strip photon detector (SSPD). Another promising area is the time-of-flight mass spectrometry (TOF MS), in which the fast ion detector with a mass-independent flat detection efficiency is strongly desired [9-11]. Although TOF MS is a powerful tool for the high-throughput biomolecular analysis, the sensitivity for high-mass molecules is low, because the detection efficiency of the conventional ion detectors, micro-channel plate (MCP) detectors degrades as the molecular mass increases over 4,000 Da. On the other hand, the superconducting strip ion detector (SSID) has the mass-independent detection efficiency due to the much smaller energy gap of several mV of a superconductor than the energy of an incident ion, which is accelerated at a few 10 keV [12]. We have been succeeded in the enlargement of the detection area of SSIDs without a degradation of the response time by using the parallel configuration [13-16]. Encouraged by those results, the 5 mm-square SSID was fabricated and its ion detection performance

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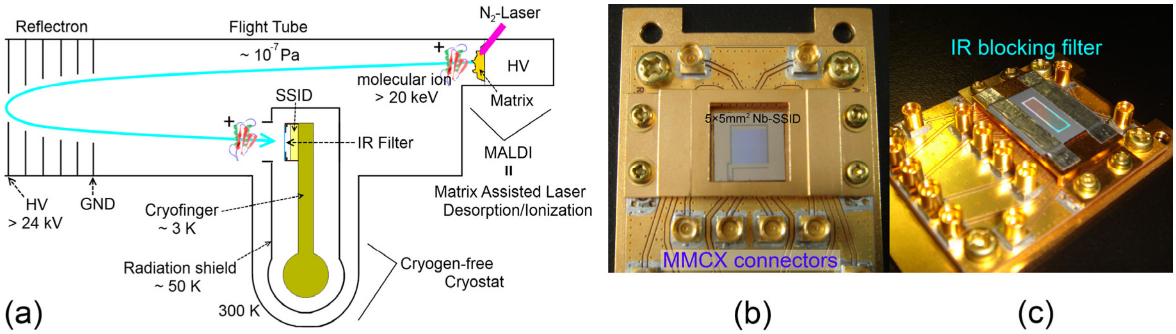

Fig. 1. (a) A schematic image of reflectron MALDI TOF MS with superconducting strip ion detector (SSID). After the laser irradiation, molecules are ionized and impinged into the flight tube by the high voltage of more than 20 kV. Ions are reflected at the reflectron and rush into the detector part. SSID is mounted on the tip of the coldfinger which is cooled down to 3.2 K by the cryogen-free cryostat. In order to suppress the invasion of thermal radiations, IR blocking filter (ULVAC, inc.) is mounted above the detector. An ion transmission rate is 35%. (b) A photograph of the detector part. A 5 mm-square SSID made of Nb is mounted at the center. Output signals are transferred through MMCX connectors. (c) A photograph of the detector part with an IR blocking filter. The filter is fixed by an electric conductive carbon tape in order to avoid the charge up of accumulated ions.

was measured.

## II. Experiments

The SSID made of niobium is mounted on the detector position of the reflectron TOF MS as shown in Fig. 1(a). The reflectron is often used for the measurement when the high mass resolution is required. The SSID is glued on the detector holder made of an oxygen-free copper by using an Apiezon N (M&I Materials Ltd.) and the copper paste. Then, the SSID is wire bondered to a coplanar wave circuit board, on which MMCX connectors are attached (Fig. 1(b)). An output signal of a SSID is transmitted through the connector. On the top of the SSID, an IR blocking filter is mounted in order to prevent a thermal radiation from heating up the detector (Fig. 1(c)) [17]. The filter is perforated by the 2 μm-diameter holes in the square lattice arrangement. The diameter is much bigger than the size of proteins and such biomolecular ions can pass through. An transmission ratio is 35%.

Figure 2(a) shows the operation principle of the SSID. The DC bias current is supplied through a bias tee. The fast output signal flows toward the preamp. In the initial stage, the shunt resistor of 50 Ω was used for preventing the latching problem but the recent study

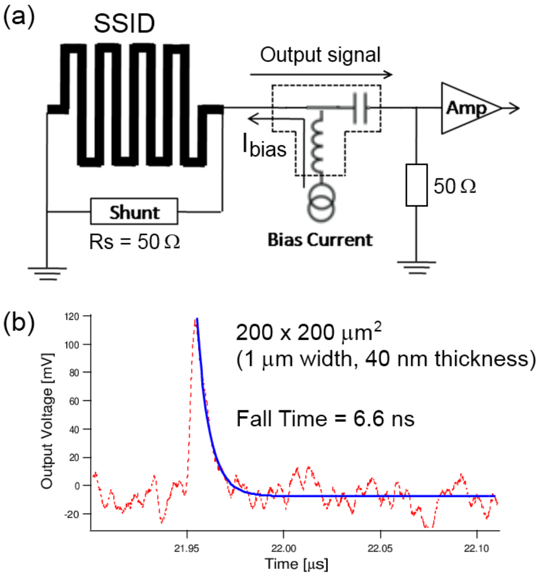

Fig. 2. (a) A schematic of an operation principle of SSID. A primitive SSID is made from a superconducting single stripline and formed into meander shape. The SSID is shunted by a resistor of 50 Ω. A DC bias current, $I_b$ which is smaller than the critical current, $I_c$ is applied through a bias-tee. An output signal is amplified by a 40 dB amplifier with a bandwidth of 10 kHz-2 GHz (HSA-X-2-40, FEMTO) whose load resistor is 50 Ω. (b) An output signal of a 200 μm-square Nb-SSID of which stripline has the width of 1 μm and the thickness of 40 nm. A fall time of 6.6 ns is obtained.

has shown that the shunt resistor is unnecessary [18]. Figure 2(b) is the output signal of a 200 μm-square SSID when an Angiotensin I (1,296 Da, polypeptide) was measured. A fall time was 6.6 ns. Hence, the simple meander cannot achieve the fast response time and the large detecting area at the same time.

Figure 3(a) shows a micrograph of a parallel-configured 5 mm-square SSID. The patterning was permormed by an i-line lithography equipment and the reactive ion etching ($CF_4$). Fifty 5 mm-long superconducting strips are connected in parallel (the number of the parallel connection, $n_p$ = 50) and form one block. Then, fifty blocks are connected in series (the number of blocks, $n_b$ = 50). An inset shows an example of a parallel-configured SSID which has $n_p$ = 5 and $n_b$ = 3.

Figure 3(b) shows an output signal of the 5 mm-square SSID when an immunoglobulin G (IgG, 146 kDa) was measured. The detector has sensitivity for such a relatively heavy proteins and shows a rise and fall times of 1.2 ns and 2.8 ns, respectively. Hence, the parallel configuration of strips is mandatory for realizing the large SSID with a fast response time. The TOF spectrum of CHCA (189 Da, Matrix molecule) is shown in Fig. 3(c). The timing uncertainty is only 1.82 ns and a good mass resolution of 5,328 was obtained.

## III. Summary

The SSID which has a detection area of 5×5 $mm^2$ with a fast response time of 1.2 ns was successfully realized. In the future, 4 pixels of them are arrayed and an 1 cm-square SSID will be achieved for a high-throughput measurement.

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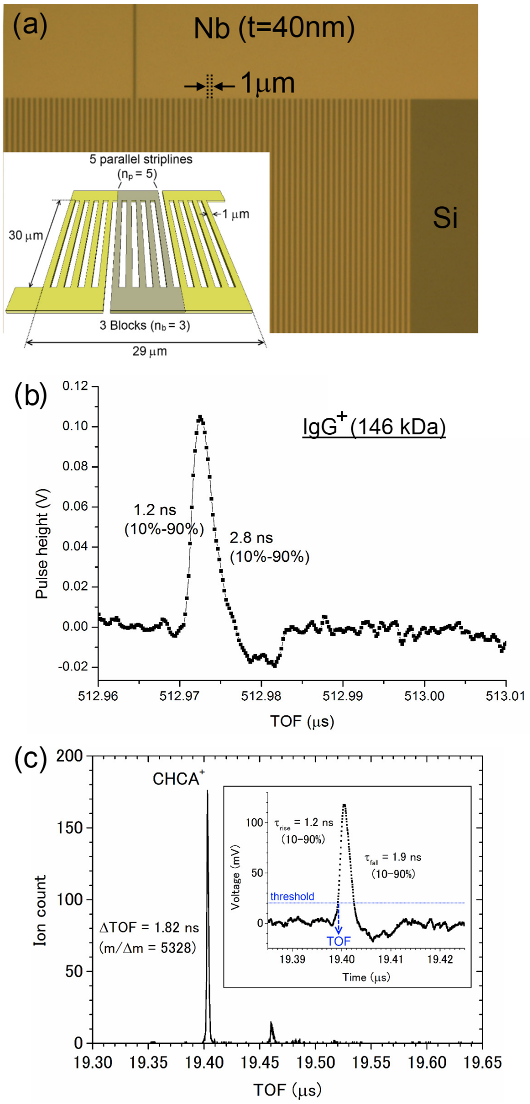

Fig. 3. (a) A micrograph of a 5 mm-square Nb-SSID of which stripline has the width of 1 μm and the thickness of 40 nm. Fifty 5 mm-long striplines are connected in parallel (the number of the parallel connection, $n_p$ = 50) and form one block. Then, fifty blocks are connected in series (the number of blocks, $n_b$ = 50). (Inset) An example of a SSID which has $n_p$ = 5 and $n_b$ = 3. The total area is 30×29 $\mu m^2$. (b) An output signal of the 5 mm-square Nb-SSID when an immunoglobulin G (146 kDa) was measured. The rise and fall time is 1.2 ns and 2.8 ns, respectively. (c) A TOF spectrum of the 5 mm-square SSID when CHCA matrix (189 Da) was measured. A mass resolution, m/Δm higher than 5,300 was obtained.

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