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A high-current scanning electron microscope with multi-beam optics

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ABSTRACT

Recently we have proposed a new Multi-beam Scanning Electron Microscope (MBSEM) which potentially offers a higher current than a single beam SEM. In this system the primary electron beam is first separated into 196 beams by an Aperture Lens Array and then focused into one single spot by using a second Micro Lens Array (MLA) in the objective lens. This system potentially offers high current (200 nA), medium resolution (50 nm), and low landing energy (500 eV) for inspection tool of semiconductor. Here we report that we have achieved a practical setup, evaluated its performance, found difficulties in operating such a system and we draw conclusions about our proposition.

1. Introduction

In the field of semiconductor technology electron microscopes (SEMs) are used in order to inspect and measure the ever smaller patterns. However, the current in a single beam system, and thus the throughput, is limited by the available brightness of the electron source and the limited aperture angle due to the aberrations of the objective lens. In order to overcome this limitation, a multi-beam SEM has been developed to deliver 196 beams to a specimen [1–4]. Such a microscope also needs 196 separate detectors which is not trivial task. In this project, we have tried to bring all beams to a single position so that one detector is sufficient, as an alternative approach for high-current SEM [5].

The whole system consists of three subsystems: the Multi-electron Beam Source (MBS), a commercial SEM column, and a Micro Lens Array (MLA) system as shown in Fig. 1. In the MBS, primary electrons are emitted from a Schottky tip and separated into 196 beams by an Aperture Lens Array (ALA) of 14×14. These beams have approximately 1 nA per beam and have the same brightness as in a single beam system. They are focused by the SEM in the plane of the 1st macro lens in MLA system. This lens has a similar function as the objective lens in a normal SEM; it images the common cross-over of the many beams onto the specimen.

The MLA system consists of three electrostatic lenses including the MLA which has 14×14 μ holes fabricated by silicon MEMS processes. In this system each beam has to be guided through an individual micro lens (hole diameter: 12 μm, hole pitch: 17 μm) and focused on the specimen. The second macrolens is a consequence of the macro electrodes that provide the electrostatic field on the aperture plate to form the micro aperture lenses, similar to the assembly in the source [2]. By careful design, this 2nd macrolens can have zero strength.

The essence of the design is that all the beams are focused at the principle plane of the 1st macro lens, so that this lens cannot contribute to either spherical or chromatic aberration. Because the aperture angle in the micro lenses is limited, the aberration contribution from these lenses is also limited. Thus, in principle, the aberration of the macro objective lens does not influence the resolution, see Fig. 1. However, the deflection by the spherical aberration of this lens (Cs deflection) still exists. It does not contribute to the spot size because the micro lenses focus each beam on the specimen independent of the deflection. The only remaining effect is that the beam may be deflected outside of the corresponding micro lens. For a further description of the system design we refer to [5].

2. Experimental setup

A schematic drawing of the MLA system is shown in Fig. 2. It is designed as an attachment for a SEM column. The system consists of four electrodes and insulators. The 1st electrode is on ground potential which could be attached to a SEM column. By applying high voltage to the 2nd electrode, we could have a 1st macro lens (objective lens) between the electrodes. The inner diameter of the electrodes is both 5 mm. The metal tube is directly attached to the 2nd electrode. 3rd electrode and the final electrode are stacked on top of the 2nd electrode. Both the metal tube and the 3rd electrode have 1.5 mm diameter hole. The final electrode has a MLA which has 14×14 holes. Meanwhile, screws are used for the connection between the 2nd electrode and the metal tube, which allow mechanical rotation adjustment to within $\pm 10°$. The other components are fixed with glue. The outer cover is used as shield for electric field immersion from the inner electrodes,

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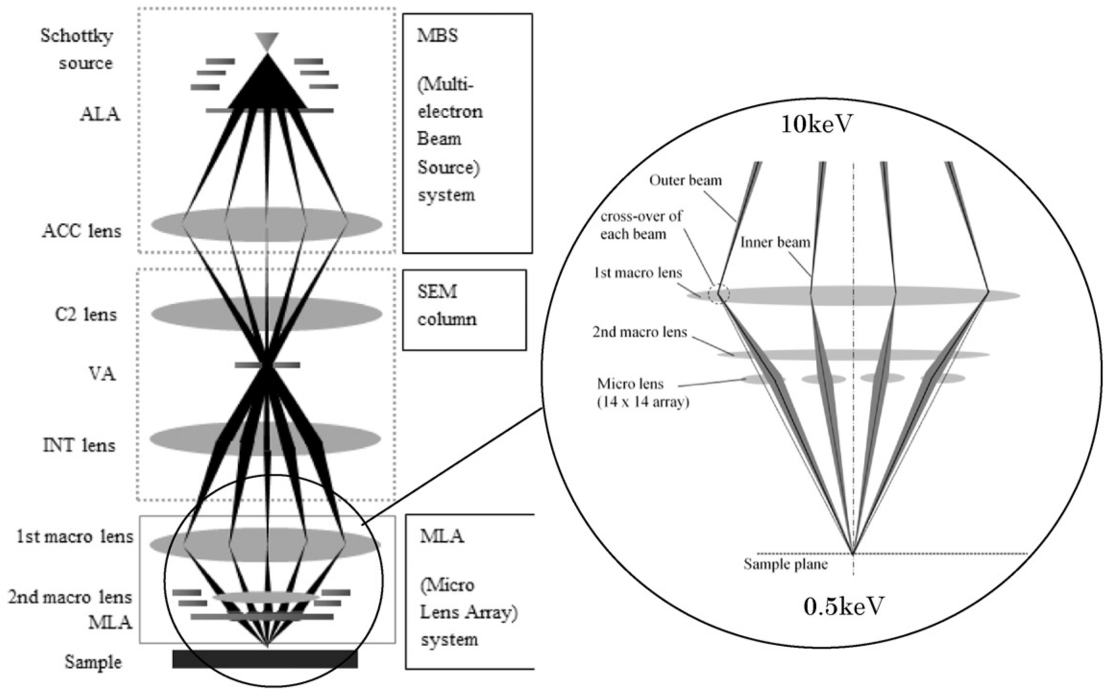

Fig. 1. Schematic drawing of total system of SEM with MBSEM optics.

which guarantees that secondary electrons can travel to the SE (Secondary Electron) detector.

In the system, the working distance between the final electrode and specimen is variable so as to evaluate the beam trajectory at different z-positions. The outer diameter of the final electrode should be as small as possible to have large detection angle for secondary electrons. The estimated potential of the electrodes is approximately 0 V (1st electrode), −8 kV (2nd electrode and metal tube), −9.0 kV (3rd electrode), −9.5 kV (final electrode, specimen, outer cover). The potential of the Schottky tip is floated at −10 kV for optimization of electron trajectories, so that the landing energy is 500 eV.

The pitch and diameter of the MLA hole is determined as 17 μm (pitch), 12 μm (diameter) respectively. Because it is too small to manufacture it by machine work, micro fabrication techniques are used. A silicon/silicon dioxide/silicon wafer was used as a base material. The top layer is 5 μm thick silicon, so that we could make micro holes on it with aspect ratio of approximately 0.4. Micro holes are manufactured with dry etching from the front side. Unnecessary layers are removed with second dry etching and wet etching from the back side. Conductivity of the electrode could be guaranteed by sputter coating with Molybdenum.

To align the system in practice, the beam position in the MLA system must be detected. A detection system was constructed with a YAG (Yttrium Aluminium Garnet) screen, in a similar set-up as used for simultaneous correlative light and electron microscopy [6]. When electrons hit the YAG screen, it emits light. In our case the YAG screen should be put on the same voltage as the MLA. Because the surface of the YAG is coated with thin aluminium layer for conductivity, it is not easy to detect 500 eV electrons. A 10 nm aluminium layer is obtained which allows both transmission of the electrons to the YAG at 0.5 keV and has sufficient conductivity. In the system, the light is detected from the backside of the YAG screen and collected by an optical lens. The light is reflected to 90° by a mirror, through a window in the vacuum chamber door. From outside of the door, the light is collected again

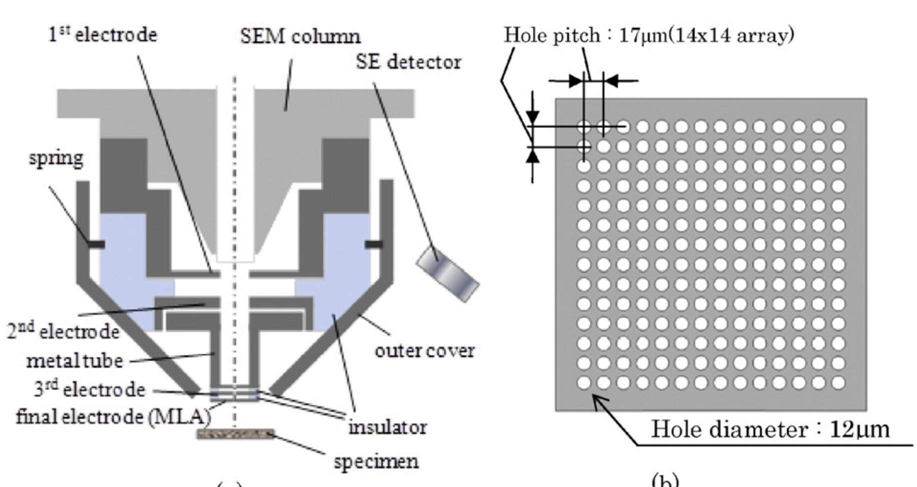

Fig. 2. Design of (a) MLA system, (b) MLA fabricated by MEMS.