Design and Fabrication of a Scanning Electron Microscope (SEM) with an Electrostatic Column for Process Embedment

Bo-Hyun Chung and Seung Jae Kim
Korea Electronics-Machinery Convergence Technology Institute, Seoul 139-743, Korea

Min Sik Choi
Department of Applied Physics, Dankook University, Yongin 448-701, Korea

Dong Young Jang
Manufacturing Systems and Design Engineering Program, Seoul National University of Science and Technology, Seoul 139-743, Korea

(Received 14 December 2012, in final form 2 April 2013)

In a scanning electron microscope (SEM), the electron beam emitted from an electron gun is focused by a lens and then scanned onto the substrate. The SEM images are obtained by detecting the secondary electrons produced by the interactions between the primary electrons and the substrate material. Currently, various kinds of products for microscopy, such as field emission (FE) SEM which uses the field emission and the helium ion microscope (HIM) which utilizes helium ions as imaging particles, are widely designed for the purpose of improving the resolution of images. However, these conventional devices are not suitable for processing because they require a high vacuum environment or because they allow easy contaminated by the plasma-forming elements. In this research a study on a mini-SEM with an electrostatic focusing lens that is applicable for material treatment in semiconductor manufacturing processes and for inspection devices was conducted. Modification of the column design in order to overcome the shortcomings of electromagnet and the bulky size by adopting an electrostatic lens will be presented.

PACS numbers: 61.72.F, 61.16.Bg, 79.40.+z
Keywords: Thermionic emission, Scanning electron microscope, Electrostatic, Column, Process embedment
DOI: 10.3938/jkps.63.1287

I. INTRODUCTION

A Scanning electron microscope (SEM) can offer images with not only higher magnification but also higher resolution beyond the limitations of optical microscopes. However, it is hardly applicable to biological samples because of its operating atmosphere of vacuum and shows difficulty in observing dielectric materials owing to its characteristic mechanism that makes use of secondary electrons. In other words, because of the high magnification of a SEM, feasible samples for SEM observation are restricted [1–3]. Although various instruments that use the phenomena of charged particle interactions, such as transmission electron microscopes (TEMs), ion microscopes, atmospheric SEMs etc., have been developed for the purpose of overcoming these demerits, some problems, such as high cost and complexity in handling, still exist.

In this study, the feasibility of using a SEM as a processing device and inspection device to enhance the productivity in semiconductor manufacture by embedding it in the process is investigated. With this, inspection of defects and control of operating conditions in real time is expected to be possible without addition of extraordinary processes. Development of a mini SEM with a monitoring system, which is likely to meet the needs described above, will be presented in this paper.

A mini SEM, like a conventional one, consists of an electron-emitting gun, a column including lenses for electron focusing, a stage for the sample mount, a detector, and electronic circuits to detect signals from secondary electrons. A thermal electron-emitting cathode was used as an electron gun in a mini SEM due to its ease of operation, and an electrostatic lens was adopted for the purpose of minimizing the column size. For the lens configuration, an einzel-type lens, which is widely used in electrostatic lens, was designed so that it might be composed of three electrodes. Even though the magneto-static lens is generally used in conventional small SEMs,
it has some shortcomings, such as increase in device size and an influence on other processes. For sample manipulation, an eucentric-type stage with 5 axis was installed.

II. DESIGN AND FABRICATION

The main purpose of electron gun is to produce high-intensity electron beams. In general, a high-intensity electron beam requires a high-brightness electron beam, and high-brightness electron beam is achieved through a high-density electron beam. In electron guns, tungsten is widely used as an electron emission material to meet this goal, and a bias voltage is applied in order to focus the beams. The brightness of an electron beam is given by following equation:

$$\beta = \frac{4I_e}{\pi^2 D_0^2 \alpha_0^2} = \frac{J_e}{\pi \alpha_0^2} \left[ \text{Acm}^{-2}\text{sr}^{-1} \right],$$  \hspace{1cm} (1)

where $\beta$ is the brightness, $I_e$ is the emitted current, $D_0$ is the source size, $\alpha_0$ is the solid angle of the emitter, and $J_e$ is the current density. As can be seen above, the brightness of a beam, $\beta$, depends on the emitted current, source size and angle. In other word, the brightness can be defined as the current density ($J_e$) emitted per unit solid angle of an electron source.

Hairpin-shaped tungsten wire is the most commonly used electron emitting agent its brightness is about $10^5$, and its lifetime is $40 \sim 100$ hours [4]. Because the interaction between the electron gun and the column depends on the conditions of the two, a higher focusing voltage is required in the column in order to obtain an electron beam with a higher acceleration energy or a higher kinetic energy. One of the major factors to be taken into consideration in the design of an electrostatic lens is the degree of vacuum which is closely related to abnormal arcs in the column. If a higher degree of vacuum is to be attained, keeping the vacuum conductance higher, which directly affects the performance of the vacuum pump with given specifications, is important.

If the beam quality is to be enhanced, effective beam focusing and removal of unfavorable electrons are essential. For this aim, two apertures with diameters of 200 $\mu$m are used in this study. Considering that above, we carried out simulations by using a conventional program, the OPERA 3D code. The simulation result for the beam

<table>
<thead>
<tr>
<th>Table 1. Specifications of the SEM with electrostatic column.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heater</td>
</tr>
<tr>
<td>Acceleration</td>
</tr>
<tr>
<td>Bias</td>
</tr>
<tr>
<td>SED</td>
</tr>
<tr>
<td>PMT</td>
</tr>
<tr>
<td>Condenser lens</td>
</tr>
<tr>
<td>Objective lens</td>
</tr>
<tr>
<td>Deflector</td>
</tr>
</tbody>
</table>

Fig. 1. (Color online) Electron beam trajectory using by Opera 3-D.

Fig. 2. (Color online) 2-D and 3-D cross sections of a column with an electron gun.

Fig. 3. (Color online) Schematics of the fabricated mini-SEM.