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Study on the recognition of the marks for low-energy microcolumn lithography

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Electron beam lithography has been paid great attention as a future lithography technology for the patterning of extremely fine structures. Generally e-beam lithography means high-energy e-beam lithography where the kinetic energies of electrons are rather high(10-100 keV). Although high-energy e-beam technology is mature and being used in the semiconductor industry, low-energy microcolumn lithography(LEML) has many great advantages as a next-generation technology, which explains the active research on the subject these days. In this study, we developed a new method to recognize the registration marks in LEML. With this novel method, there is no need to supply a bias to the mark electrodes, which remarkably simplifies the fabrication process of IC devices.

Key words: Low-energy lithography, Microcolumn, Recognition of the registration mark, PMMA resist, SiO_2/ITO.

Introduction

Recently there is very active research on electron-beam (e-beam) lithography as a future lithography technology that can make the fine patterns with a line-width less than 20 nm [1, 2]. Since the wavelength of an electron beam is much shorter than that of optical waves, e-beam lithography is rather free from diffraction that fundamentally limits the resolution of today's optical lithography. With e-beam technology, it is easy to pattern lines with a width of less than 10 nm.

E-beam lithography usually means high-energy e-beam lithography where the kinetic energies of electrons are rather high (10-100 keV). The high-energy e-beam technology is mature and being used in the semiconductor industry, for example, in the fabrication of the optical masks. On the other hand, there has also been steady research activity on low-energy (< ~1 keV) e-beam lithography where the patterning is carried out in a tiny device called a microcolumn. Low-energy microcolumn lithography has many considerable advantages as a next-generation technology.

The most outstanding feature of LEML is the possibility of multiple patterning through operation of many microcolumns at the same time, which will overcome the poor productivity of conventional e-beam lithography and make it possible for the semiconductor industry to use e-beam technology for mass production [3]. Besides, the low-energy electrons cause little mechanical damage to the materials being processed and have a very small proximity effect caused by electron scattering that results in degradation of image quality.

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One of the problems that e-beam lithography has is the alignment of the circuit die being processed. In the case of high-energy e-beam lithography, the mark used for the alignment (called a registration mark) in the die is negatively biased through the connection electrode [4] in order to slow down the incoming electrons. The kinetic energies of electrons are so high that the registration mark can be located even when the wafer is covered with a very thick (~ 200 nm) resist. Hence a negative bias can protect the mark from the mechanical damage by decreasing the electron energy. But the electric field generated from the mark may cause distortion of the e-beam path that, in turn, results in a position error of the circuit patterns.

For LEML, the mark does not have to be negatively biased and the connection electrode is not needed either, since the electron energy is sufficiently low not to worry about the mechanical damage caused by electrons. The removal of the electrode is desirable because it simplifies the lithographic process. It is, however, true that the low energies of incoming electrons make it difficult to find the registration mark.

In this study, we propose a novel method to recognize the registration mark in LEML. With this new method, the mark can be found easily despite the low energies of incoming electrons and a connection electrode to the mark was not implemented to make use of the considerable advantage of low-energy e-beam lithography.

Experiments

To carry out LEML, the pressure of the processing chamber should be kept below 10^{-8} torr (1.33×10^{-6} Pa). To maintain such a high vacuum state, we have developed a microcolumn lithography system composed of a load-lock chamber and a main chamber. In the load-lock chamber, the new die sample can be loaded and exchanged with the die that went through the e-beam lithography process in the main chamber. Therefore the main chamber does not have to be exposed to the atmosphere and can always be kept at a low pressure.

We have prepared two types of samples to test our new mark-recognition method. One types of sample consisted of a silicon substrate coated by a 100-nm SiO_2 film. The other sample was a piece of glass on which 100-nm indium tin oxide (ITO) film was deposited. We patterned the SiO_2 and ITO registration marks on the silicon and glass substrates, respectively, through a conventional optical lithography process-photo resist (PR) coating, baking, exposure, development, etching, and cleaning. Fig. 1 are micrography of the registration mark on each substrate. The patterned samples were cleaned using an ultrasonic washer and coated with 17-nm PMMA resist using a spin coater for 5 seconds under with a spinning rate of 4,000 rpm.

The PMMA-coated samples were set in our microcolumn lithography system. We tried to identify the registration mark by observing the back-scattered electrons (BSE) that were generated from the sample when we illuminated the sample with low-energy electrons. The kinetic energy of illuminating electrons were around 500 eV and the image of BSE was obtained by back-scattered electron detector (BSD). The BSD was located very near to the sample surface to collect as many electrons as possible.

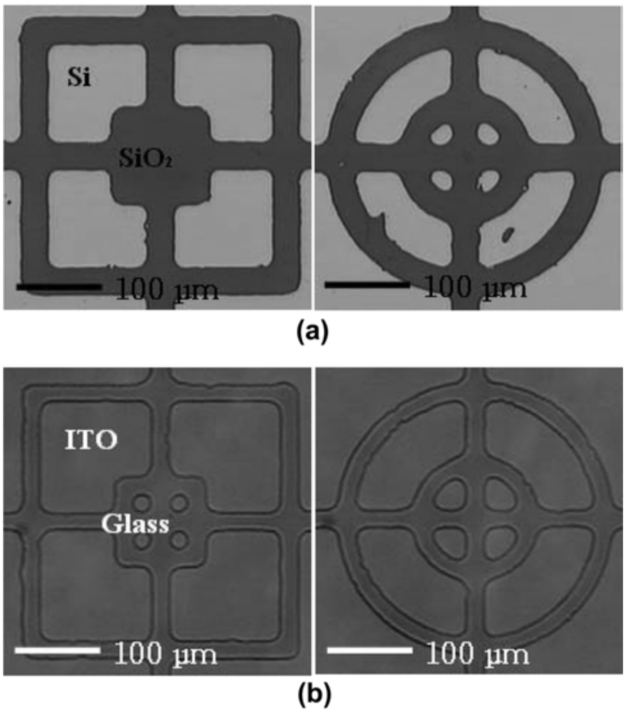

Fig. 1. Micrographs of (a) SiO_2 registration mark patterns on Si and (b) ITO registration mark patterns on glass.

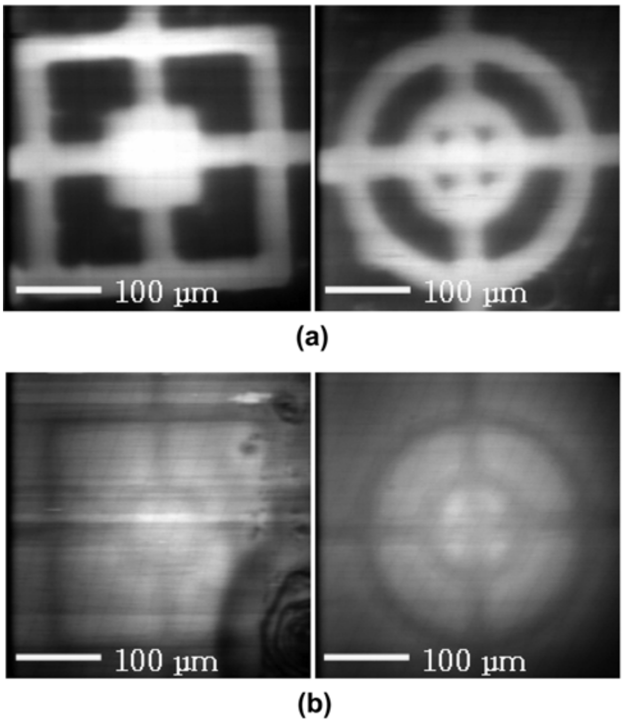

Fig. 2. Back-scattered electron detector(BSD) images of (a) SiO_2 registration mark patterns on Si and (b) ITO registration mark patterns on glass.

Results and Discussion

Fig. 2 shows images of die samples captured by the BSD. As one can see, the registration marks are easily identified. The graph in Fig. 3 is the BSE intensity measured along line 2 of Fig. 3. One can notice that the BSE intensity was strongly dependent on the underlying material below the Polymethyl Methacrylate (PMMA) resist where the electrons arrived. As one can see in Table 1, the BSE intensity from SiO_2 positions was three times larger than that from positions where the silicon substrate was underlying. For the ITO/glass sample, the intensity difference was smaller compared with the SiO_2/Si sample, but large enough to distinguish the ITO registration mark clearly from the glass substrate.

Such a difference can be explained as follows. Many electrons could reach the substrate since the penetration depth of 500-eV electrons in PMMA resist is 15-20 nm [5]. Therefore the substrate and registration mark are negatively charged by incident electrons whose number increases as the e-beam continues to irradiate the die sample. Also some of the electrons in the surface of substrate or registration mark are scattered back to the vacuum when the incoming electrons hit the surface. The number of back- scattered electrons depends on the attractive force that the material imposes on the electrons. Therefore the BSE intensities are different from each other according to the materials where the back-scattering take place, and it would be desirable to select materials for the substrate and registration mark whose attractive forces on electrons are substantially different.

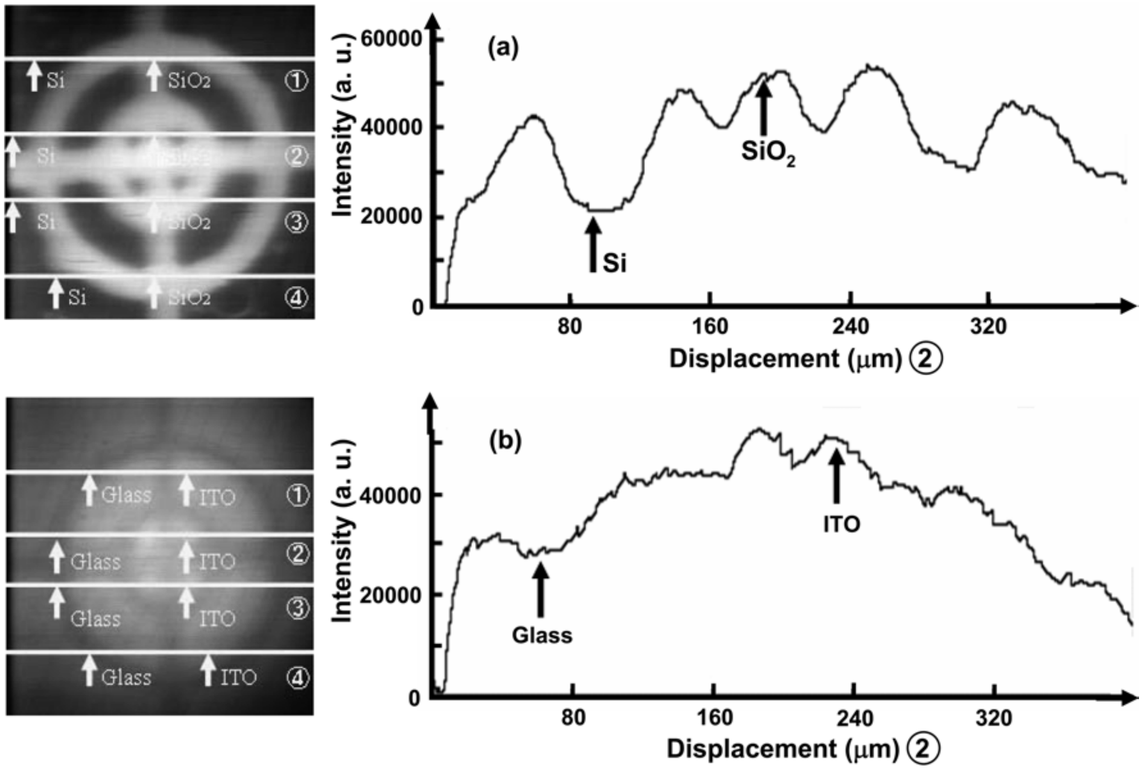

Fig. 3. A comparison of the BSE intensity between (a) SiO_2/Si and (b) ITO/glass measured along line 2.

Table 1. Mean values of BSE intensity of SiO_2, Si, ITO, and glass

Materials	Line 1	Line 2	Line 3	Line 4	Average
SiO_2	42500	52500	55000	57500	51875
Si	15000	20000	15000	20000	17500
ITO	42500	50000	45000	30000	41875
Glass	25000	30000	32500	22500	27500

Conclusions

While low-energy microcolumn lithography has great advantages as a future semiconductor processing technology, several problems remain. The alignment of the circuit die is one of the main problems that should be solved for the practical application of LEML in the semiconductor industry.

In this study, we have proposed a novel method to recognize the registration mark of the circuit die in LEML, which can be a direct solution of the alignment problem. The electrode connected to the registration mark is not needed in our method, which saves many complicated processing steps required to form the electrode.

We have used the BSE intensity to identify the registration mark and obtained clear images of the marks that were made of SiO_2 on silicon- and ITO on glass-substrates. We expect that our method will be an effective and practical solution for the alignment problem in LEML, and contribute to the development of LEML as a next-generation lithographic technology.

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