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EUV Lighting with C-beam Irradiation Technique for Ultra-High-Resolution Devices

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ABSTRACT

High-resolution lithography is required for ultra-high-resolution pixel of next-generation display devices. For high-resolution lithography, EUV lighting using carbon nanotube (CNT)-based cold cathode electron beam (C-beam) was studied. EUV lighting is affected by C-beam irradiation conditions. In addition, the possibility of high-resolution lithography was confirmed by using polymethyl methacrylate.

1 Introduction

Display devices can be seen anywhere in our daily life. As activities in virtual space are in the spotlight, interest in promising next-generation displays such as virtual reality (VR) and augmented reality (AR) is increasing. For VR and AR, technological advances in software and hardware systems are required. One of these is resolution density improvement. In the case of conventional display devices such as TVs and monitors, the resolution was appropriate due to the relatively long viewing distance. However, in AR and VR, a higher resolution density than 2000 ppi is required because the viewing distance is relatively short [1]. Fine metal mesh is used for display devices with a resolution of about 600-800 ppi [2]. Different approaches are needed for high-resolution density for VR and AR, and high-resolution lithography for next-generation display is one of the alternative technologies [3].

Currently, based on the development of light sources and optical technology, semiconductors in the region of a few nanometers are being fabricated [4]. Advanced light source manufacturing technologies are required for high-resolution lithography, and A light source that has recently been attracting attention is EUV lighting. Laser-produced plasma is mainly used for EUV lighting, but there are disadvantages of being expensive and bulky [5].

Vacuum nano-electronic devices can be scaled down to the millimeter size based on vacuum tube technology [6]. Various electron emission sources are being studied for vacuum nano-electronic devices, and one of these is a carbon nanotube (CNT)-based cold cathode electron beam (C-beam). We fabricated ultraviolet (UV) light sources with various wavelengths using C-beam [7].

Through the C-beam, electrons are irradiated into the wide bandgap materials to obtain large-area UV light from UVA to UVC. Based on these studies, we fabricated EUV lighting by irradiating electrons emitted from the C-beam directly onto metal target. In EUV lighting, EUV intensity is affected by C-beam irradiation conditions. Using these characteristics, C-beam technology for high resolution lithography will be discussed.

2 Experiment

The key to lighting using C-beam is the use of CNT emitters. A mesh gate is used for electron extraction in CNT emitters, as shown in Fig. 1(a). Fig. 1(a) is a schematic diagram of EUV generation by C-beam. The electrons emitted from the C-beam excite metal to generate EUV light. Fig. 1(b) is an SEM image of CNT

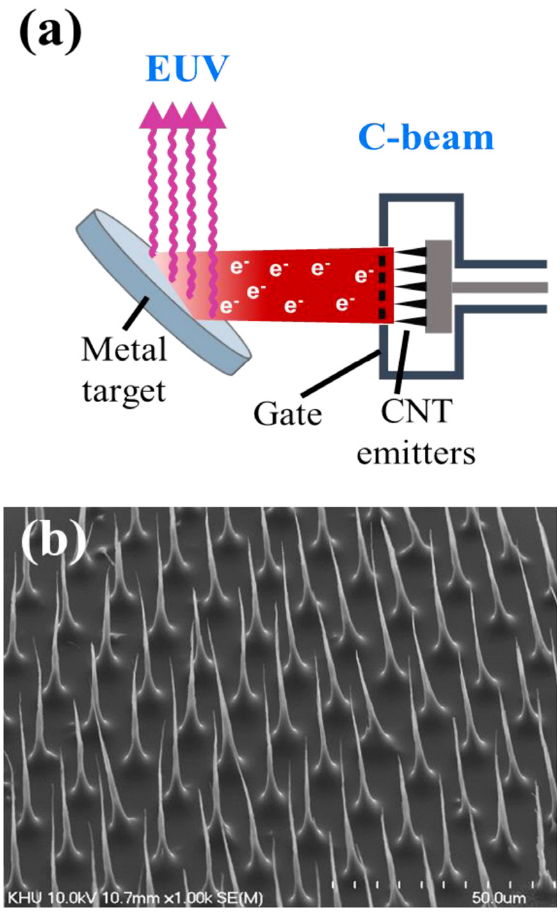

Fig. 1. (a) Schematic of EUV lighting with carbon nanotube-based cold cathode electron beam (C-beam) irradiation. (b) SEM image of CNT emitters for EUV lighting.

emitters viewed from the 45 degrees direction. CNT emitters grown vertically using DC-PECVD have a height of 40 μm and are consistently well synthesized with a desired spacing of 15 μm.

3 Results and Discussion

By irradiating C-beam on the metal target, EUV light generation and intensity change were confirmed using EUV photodiode. To confirm high power EUV lighting, we demonstrated multi-beam exposure technique. C-beam arranged with 90-degree angle and irradiated simultaneous to observe light intensity changes. The EUV light intensity measured with UV photodiode and low energy filter. The Zr based low energy filter could filtering less than several tens nanometers. Fig. 2 shows the photo responsivity of photodiode with various wavelength. The photodiode shows higher photo responsivity between 10 to 20 nm ranges. So, we select this diode to measure relative EUV light intensity.

EUV intensity is affected by C-beam irradiation conditions such as anode voltage, current, and electron incident angle. EUV intensity is enhanced with increased voltage and current. The EUV light intensity increases with anode bias increasing. The increases come from multiple interaction of electrons with core, Sn atoms in the anode. The number of scattering of electrons with atoms depends on the anode bias, which electron energy. If anode bias is too high then heat generation is higher, resulting less efficiency of EUV light. Also, EUV light intensity increases with anode current at constant anode bias. However, the higher anode current appears the higher anode heating, resulting anode meting and less EUV lighting efficiency.

The debris generation effect was confirmed with pressure changes inside of the EUV lighting chamber. When input power (anode current times anode bias) is higher than melting temperature of anode Sn target, we could observe pressure increases. The pressure changes tell us that anode Sn is melted and vaporized. The melting temperature of Sn is 231.9 degree Celsius, so it is easily vaporized with high power irradiation. However, I f we irradiate Sn anode with moderate power, we could not find pressure changes. Resulting no debris generation.

Based on these results, the possibility of high-resolution lithography of EUV lighting using C-beam irradiation was confirmed using polymethyl methacrylate (PMMA) as a photoresist. Blank exposure technique used for the lithography. The blocked area and non-blocked area be distinguished after development. The PMMA react with more than 10 eV irradiation energy.

The characteristics of EUV lighting according to C-beam irradiation conditions, and details of EUV performance would be presented.

4 Conclusions

In summary, EUV lighting was developed using CNT emitters as field emitters. Electrons emitted from the C-beam are directly irradiated to the metal target to generate

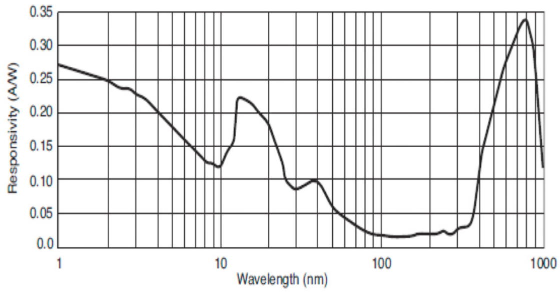

Fig. 2 Photo-responsivity of the used photodiode (SXUV100DS) to measure relative EUV intensity.

EUV light, and its characteristics vary depending on the C-beam irradiation conditions. In addition, the applicability of high-resolution lithography of EUV lighting was confirmed by using PMMA as a photoresist. Lighting technology using C-beam is expected to be applied to achieve high-resolution density of next-generation display devices such as AR and VR and to develop advanced lithography technology.

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