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Nanosilicon dot arrays with a bit pitch and a track pitch of 25 nm formed by electron-beam drawing and reactive ion etching for 1 Tbit/in.^{2} storage

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The formation of very fine Si dots with a bit pitch and a track pitch of less than 25 nm using electron-beam (EB) lithography on ZEP520 and calixarene EB resists and CF_4 reactive ion etching has been demonstrated. The experimental results indicate that the calixarene resist is very suitable for forming an ultrahigh-packed bit array pattern of Si dots. This result promises to open the way toward 1 Tbit/in.^{2} storage using patterned media with a dot size of <15 nm. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2400102]

Available magnetic recording density is rising at a rate of 60% per year. High-end magnetic storage media with a recording density of over 100 Gbit/in.^{2} have already been commercialized. In optical recording, the Blu-ray disk and the high-definition digital versatile disk (DVD) with a capacity of 25 Gbytes have also been developed. However, there are many technical issues to be solved for recording densities as high as 1 Tbit/in.^{2}. A breakthrough is required for future recording systems. Today, we have some technical proposals such as patterned media[1] and near field optical recording[2] which address the above issues.

Electron-beam (EB) lithography is expected to allow the formation of very fine pit or dot arrays for patterned media and next generation DVDs. Many variations of EB drawing (exposure) have been developed to allow the fabrication of semiconductor devices and optical disks.[3–5] So far, pit patterns with a minimum bit pitch (BP) and track pitch (TP) of 40 and 80 nm, respectively, have been achieved on ZEP520.[6] Furthermore, the formation of very fine dot arrays using calixarene has been reported by Fujita and co-workers.[7,8] They demonstrated the formation of 15 nm diameter dot arrays with 100 and 60 nm pitches for quantum devices and magnetic recording media. These recording media were, however, very far from the areal density of 1 Tbit/in.^{2}, because the pitches were too large. In this letter, we describe the ultrahigh-packed nanofabrication of a 1 Tbit/in.^{2} storage medium using EB exposure and reactive ino etching (RIE).

In order to achieve fine bit arrays with densities of over 1 Tbit/in.^{2}, we carried out (1) a very fine EB exposure with a fine probe and a high probe current; we also prepared (2) a thin resist layer to prevent the spread of incident electron scattering; finally, we designed (3) a highly packed pattern with a hexagonal or centered rectangular lattice structure such as cross stitch to prevent proximity effects. Item (2) refers to a thin resist layer which requires an increased acceleration voltage for precise EB drawing. We used a resist layer with thicknesses of 70 and 15 nm for ZEP520 and calixarene, respectively. The minimum thicknesses were determined so that the layer would suffer no deformation and would allow sufficient contrast in scanning electron microscopy (SEM) observation after exposure and development. Calixarene is so tough under electron irradiation that we were able to use layers as thin as 15 nm.

Our EB drawing system consists of a high-resolution SEM (JSM6500F, JEOL, Ltd.) with an in-lens-type Schottky-emission field-emission electron gun for high probe current with a fine probe, and an EB drawing controller (Tokyo Technology Co., Ltd.).[9] We used the system at a probe current of 100 pA and an acceleration voltage of 30 kV because a fine probe less than 2 nm in diameter was obtained. In the drawing, the address resolutions were 10 and 2.5 nm on the ZEP520 and calixarene resists, respectively. The development process was carried out using the commercial developers ZED-N50 (MIBK+IPA) and ZEP-RD (xylene) for 210 and 180 s using ZEP520 and calixarene, respectively.

We carried out EB exposure using ZEP520 resist for dot arrays with a BP of <100 nm and a TP of <70 nm. Figure 1 shows SEM images of the ZEP520 resist patterns drawn at an exposure dosage of around 190 μC/cm^2. After the exposure, we developed the sample by dipping it into the developer. The figure shows pit arrays with a minimum pit diameter of <20 nm at a BP of 60 nm and TPs of 50 and 40 nm, formed in the ZEP520 resist. We were unable to form higher-packed pit patterns in the ZEP520 resist than that shown in Fig. 1(b). The pit size also fluctuated at a BP of 60 nm and a TP of 40 nm [Fig. 1(c)]. The deviation became large, reaching about 18 nm with increasing exposure dosage, while it was about 11 nm in the pattern with a BP of 100 nm and a TP of 50 nm. The fluctuation gradually increased with increasing packing. This means the high-density packing patterns are not useful in optical and magnetic storage media. The results indicate that the pit array pattern at a BP of 60 nm and a TP of 40 nm has the highest density in the case of EB drawing on ZEP520 resist. The highest-density pattern corresponds to about 540 Gbytes/in.^{2} when using edge modulation recording (EMR) for optical read only memory applications.

We tried to form higher-packed patterns using calixarene with a thickness of about 15 nm. Figure 2 shows SEM images of ultrahigh-packed dot array resist patterns. The exposure dosage was 34–40 mC/cm^2. In the experiment, we successfully formed a 30 nm pitch pattern [Fig. 2(a)], and it was almost possible to form a 25 nm pitch pattern although we required very fine adjustment of EB focus [Fig. 2(c)]. The

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