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Microstructure and recording mechanism of Bi–Fe–(N) layer for high-density write-once optical disk

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Bi–Fe–(N) thin film as the recording layer of high density digital versatile disk recordable optical disk was developed. For the disk sample with optimized layer structure, maximum partial response signal to noise ratio of 21.1 and minimum simulated bit error rate of 5×10^{-7} were achieved at the write power=5.7 mW. Transmission electron microscopy characterization illustrated that the separation of Bi and Fe elements to form the coarse granular structure in the mark regime during laser irradiation comprised of the recording mechanism. © *2008 American Institute of Physics*. [DOI: 10.1063/1.2828335]

Optical disks are the most important external storage devices for contemporary information management due to their large recording capacity, interchangeability, and portability.[1,2] A main development trend of optical disks is to increase the recording capacity as it can be seen from the evolution of compact disk[3] into digital versatile disks (DVDs).[4] Presently, high density DVD (HD DVD) and Blu-ray (BD-R) disks are recognized as the next-generation recording media.[5]

For write-once disks, various organic and inorganic recording materials have been proposed.[6] Inorganic-type materials include phase-change alloys,[7] single-layer AlSi alloys,[8] bilayer metals such as Cu/Si,[9] Zn/Ge,[10] Ge/Au,[11] Cu/*a*-Si,[12] etc. Among these, Bi-related alloys such as Bi–Ge alloy[13,14] and Bi oxide (BiFeO)[15,16] exhibit promising applications for write-once data storage. For Bi–Ge–(N) alloy, the recording mechanism was attributed to the reflectivity change caused by the decomposition of Bi nitride in the recording layer as well as the deformation in recording marks due to the gas release.[14] As to the BiFeO, the signal recording was resulted from the crystallization of Bi and BiO.[16]

This work studies the feasibility of Bi–Fe–(N) recording layer to HD DVD recordable (DVD-R) optical disks and the recording mechanism. Optical disk samples were prepared in accord with HD-DVD specifications[17] via sputtering process. The multilayer disk structure is PC substrate/Ag (100 nm)/$ZnS-SiO_2$ (23 nm)/Bi–Fe(N) (10 nm)/$ZnS-SiO_2$ (40 nm)/PC substrate. The Bi–Fe–(N) layer was deposited by the sputtering of Bi–Fe alloy target under Ar/N_2 gas flow at the working pressure about 2 mtorr. The x-ray photoelectron spectroscopy (XPS) (ULVAC-PHI) revealed the average composition of Bi–Fe–(N) layer as $Bi:Fe:N\approx40:57:3$ (in at. %). Dynamic tester (ODU-1000, PULSTEC) equipped with a 405 nm laser diode and a numerical aperture of 0.65 was adopted to evaluate the optimum write power (P_w) and signal properties of disk samples at the conditions of clock frequency=64.8 MHz, linear speed=6.61 m/s and the track pitch=0.4 μm.

Figure 1 plots the partial response signal to noise ratio (PRSNR) and simulated bit error rate (sbER) as a function of P_w of disk samples deduced by dynamic test. In addition to the good sensitivity of Bi–Fe–(N) disk sample at low P_w, the optimized disk sample achieved the maximum PRSNR of 21.1 and the minimum sbER of 5×10^{-7} at P_w=5.7 mW, as shown in Fig. 1, exceeding the requirements of HD-DVD specifications.[17] The eye pattern corresponding to the signals ranging from 2 to 11 T read directly from oscilloscope is shown in Fig. 2. The distinct signal tones evidence the random signals could be written perfectly in Bi–Fe–(N) disk samples.

Figure 3 presents the micrograph of signal marks in a recorded disk sample taken by transmission electron microscopy (TEM) (Jeol FX-II 2010).[18] Distinct, seashell-like signal marks with various recording lengths can be seen. Selected area electron diffraction (SAED) patterns taken from the nonmark and mark areas both exhibit the vague ring patterns, indicating that the Bi–Fe–(N) layer remains amorphous prior and posterior to laser writing. This is opposite to conventional disks in which the recording mechanism always

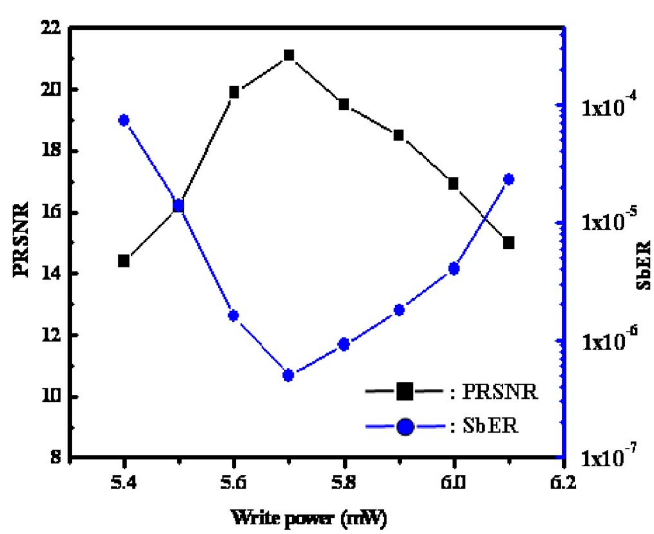

FIG. 1. (Color online) Variation of PRSNR and sbER of disk samples vs the write power (P_w).

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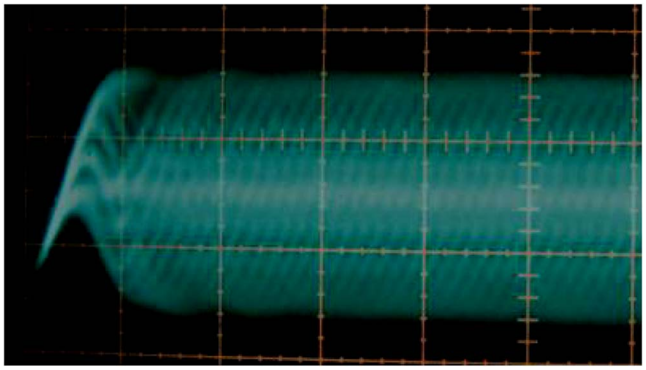

FIG. 2. (Color online) Eye patterns of random signals read directly from oscilloscope.

relies on the amorphous-to-crystalline phase transitions.

Figure 4 presents the variations of chemical compositions in a signal mark and its vicinity deduced by energy dispersive spectroscopy (EDS) (Link ISIS 300). Outside of the mark, the Bi and Fe elements are uniformly distributed while inside the mark, the Bi and Fe element distributions vary irregularly. This implies a distinct element separation in the Bi–Fe–(N) layer subjected to laser irradiation. The Bi–Fe binary alloy phase diagram indicates the room-temperature solid solubility of Fe in Bi is rather small and the Bi is nearly insoluble in Fe.[19] According to above TEM/EDS analysis, it was speculated that the laser thermal energy causes the element separation in the molten Bi–Fe and then, at the completion of signal recording, the fast quenching rate results in the formation of amorphous, irregular Bi-rich and Fe-rich solid solution phases. The element separation in conjunction with the coalescence/coarsening of separated phases consequently provided sufficient optical property change for signal readout in Bi–Fe–(N) disk samples.

Figure 5 shows the TEM micrograph of as-deposited Bi–Fe layer. The attached SAED pattern illustrates the

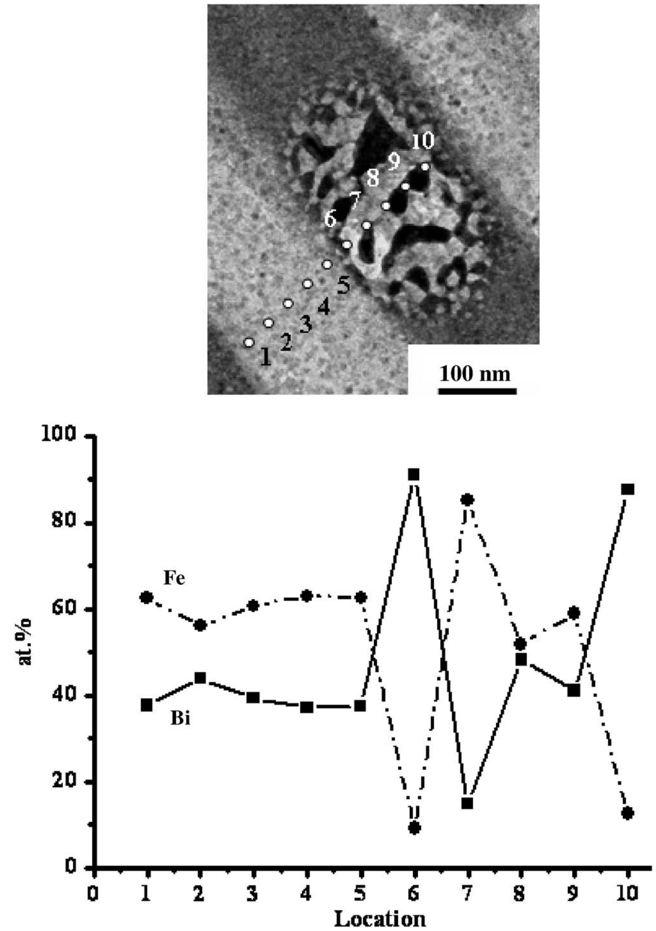

FIG. 4. Variations of chemical compositions deduced from the EDS analysis in the mark and its vicinity. Locations of EDS analysis are specified in inserted TEM micrograph.

nitrogen-free film is polycrystalline. Dark, coarse grains within the sizes of 50–70 nm embedded in fine grains within the sizes of 10–20 nm can be readily seen. EDS analysis revealed the coarse grains are Bi-rich (Fe content <14 at. %)

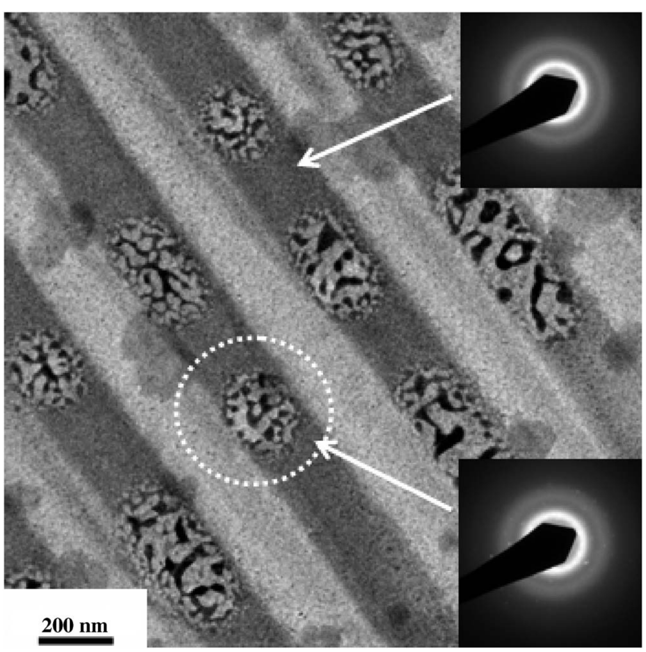

FIG. 3. TEM image of recording marks in an optical disk sample. The SAED patterns attached on upper and lower right-hand corners of TEM image were taken from the nonmark and mark areas, respectively.

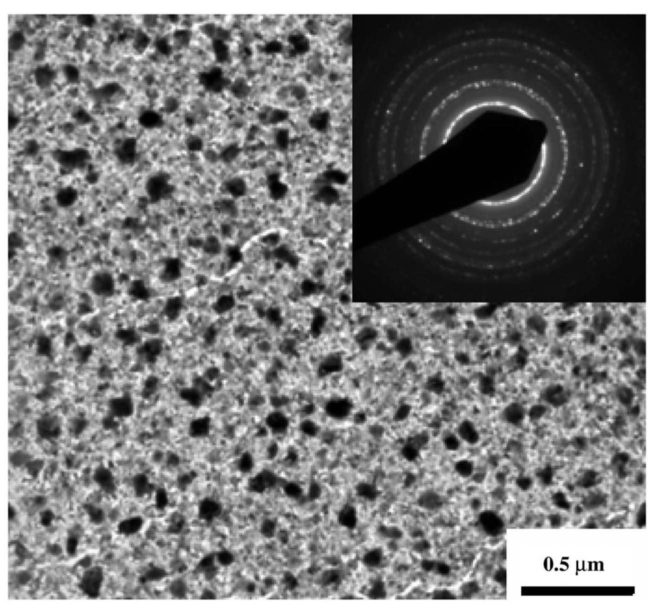

FIG. 5. TEM micrograph of as-deposited Bi–Fe layer. The attached SAED pattern indicates that the film is polycrystalline and dark, coarse grains are Bi-rich phase as revealed by EDS analysis.

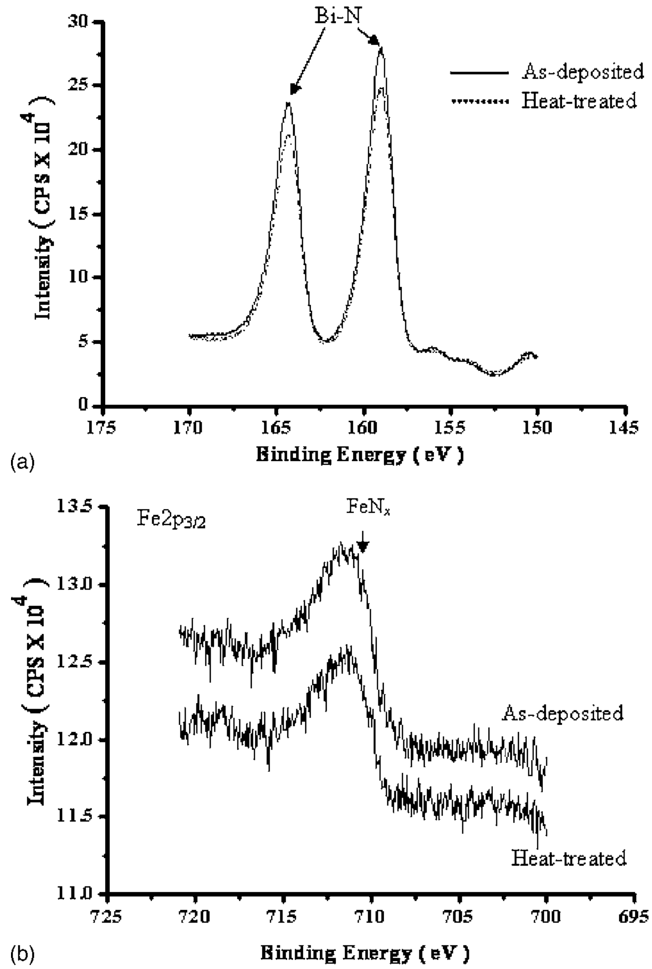

FIG. 6. XPS peaks of (a) Bi–N and (b) Fe–N bonds in an as-deposited and a Bi–Fe–(N) layer subjected to a rapid heating to 400 °C.

phase and the fine grains are mixed phases with average composition as Bi:Fe≈2:3 (in at. %). Signal properties of disk samples containing Bi–Fe recording layer were evaluated by dynamic tester; nevertheless, none of them satisfied the HD DVD-R specifications. Though the shell-like marks could form in recorded disk, they were embedded in a coarse polycrystalline strcture. The structure discrepancy of mark and nonmark areas in Bi–Fe disk samples is hence unable to induce sufficient optical property change for signal readout. This evidences that the introduction of nitrogen gas during the sputtering deposition of recording layer is essential in producing a fine, amorphous background structure in Bi–Fe–(N) disk samples. It exaggerates the optical property change of mark and nonmark areas and hence results in satisfactory signal properties of optical disks.

In order to further clarify above arguments, the Bi–Fe–(N) layer was heated at a rate about 100 °C/min to 400 °C, cooled down immediately in nitrogen ambient, and then transferred to XPS for analysis. The Bi–N (Ref. 14) and Fe–N (Ref. 20) bonds were identified, as revealed by the XPS spectra shown in Figs. 6(a) and 6(b). The introduction of nitrogen gas during sputtering results in the formation of those nitrides and they effectively induce the structure refinement in the Bi–Fe–(N) layer. The nitrides also inhibit the long-range ordering of atoms during signal writing and imply the amorphism of recorded marks. It is noted that Bi element signal is absent in the XPS peaks shown in Fig. 6(a), indicating the Bi–N nitride does not decompose during laser writing. We evaluated the surface morphology of a recorded disk samples by an atomic force microscope (Nano Scope Dimension 3100) and found no periodic bulge up on the disk surface. Hence, the formation of nitrogen gas bubbles caused by the decomposition of nitrides in recorded marks was expelled from the recording mechanism of Bi–Fe–(N) disk samples.[14,21,22]

In summary, we demonstrate the feasibility of Bi–Fe–(N) layer as the recording media in HD DVD-R optical disks. PRSNR of 21.1 and sbER of 5×10^{-7} were achieved at P_w=5.7 mW in the optimized disk sample. TEM/EDS characterization revealed the coarse Bi- and Fe-rich solid solution phases comprise of the signal marks in disk samples. A notable feature in the Bi-Fe-(N) disk samples is the mark area remains amorphous after signal recording. The optical property change of Bi–Fe–(N) recording layer required for signal readout was resulted from the distinct grain size change and element separation, rather than the amorphous-to-crystalline structure change as in conventional optical disks. Nitride decomposition and nitrogen gas release in recording layer were not ascribed to the recording mechanism of Bi–Fe–(N) optical disk samples.

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