New High Density Recording Technology: High K_u Magnetic Materials

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ABSTRACT

In collaboration with Tohoku University, Fuji Electric has realized the first successful synthesis of a $L1_1$ type CoPt ordered alloy film having a high magnetic anisotropy constant K_u using sputter technique. The K_u value of this material reached a maximum value of 3.6×10^7 erg/cm^3. Moreover, this material is superior to other ordered alloys even if the order is low and the K_u value is high. Also, a ternary alloy formed by adding Ni to this material is capable of maintaining a crystalline structure and a high K_u value over a wide compositional range while controlling the saturation magnetization M_s. For example, with a ternary alloy having the same magnetic characteristics as a binary alloy of rare Pt at 75 at%, the amount of Pt can be decreased to 25 at%.

1. Introduction

The recording densities of perpendicular magnetic recording media have been steadily increasing. Fuji Electric presently produces 2.5-inch disk having the capacity of 320 GB (recording density of approximately 500 Gbits/in^2). To achieve even higher recording densities in the future, several technical challenges must be overcome. Amongst these, the most formidable technical challenge is preventing degradation of thermal stability in the recording bits, even when miniaturized. The expression $K_u V/k_B T$ (K_u: magnetocrystalline anisotropy constant, V: volume, k_B: Boltzmann constant, and T: absolute temperature) has been used as an indicator of thermal stability. In the design of magnetic recording media, the reduction in magnetic grain volume V accompanying miniaturization of the recording bits must be compensated with an increase in K_u, but the K_u value of the Co-Pt magnetic material having a hcp (hexagonal close-packed) structure and being generally used in the recording layer of perpendicular magnetic recording media at present is limited. Therefore, to realize higher densities in the future, new magnetic materials having an extremely high K_u value, in the order of 10^7 erg/cm^3, must be developed.

Typical magnetic materials having such a high K_u value are Co-Pt binary alloys with an $L1_0$ structure. Additionally, ordered alloy films[(1),(2)] of the type known as m-$D0_{19}$, and $L1_1$ type[(3)] Co-Pt ordered alloy films have been reported. Fig. 1 shows a schematic structure of these ordered alloys.

The aforementioned m-$D0_{19}$, and $L1_1$ type ordered alloy films have been reported to be formed at substrate temperatures ranging from 300 to 400 °C[(1)~(4)]. This range is 200 to 300 °C lower than the typical formation temperature of $L1_0$ type Fe-Pt ordered alloy film, which is also a high K_u thin film, and because the manufacturing process temperature can be limited to a low level, this is extremely advantageous for application to magnetic recording media.

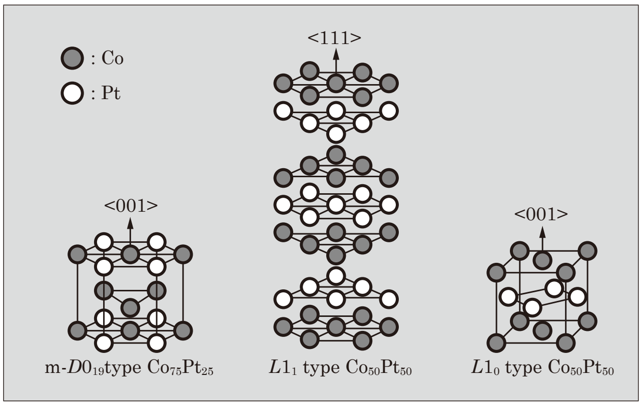

Fig.1 m-$D0_{19}$, $L1_1$ type and $L1_0$ type crystalline structures

However, these m-$D0_{19}$, and $L1_1$ type ordered structures are all metastable phases, and in the major reported cases, were grown epitaxially by MBE (molecular beam epitaxy) on a single crystal substrate in an ultra-high vacuum. These metastable ordered alloys, if they can be formed not by MBE, which is difficult to use in mass-production, but by the sputtering process presently used in the mass-production of magnetic recording media, hold promise as materials having a high K_u value on the order of $L1_0$ type Fe-Pt ordered alloy film.

Fuji Electric, in collaboration with Tohoku University, has applied a UHV (ultra high vacuum) sputtering process to fabricate these m-$D0_{19}$, and $L1_1$ type metastable ordered alloys and has successfully obtained K_u values of 3×10^7 erg/cm^3 or higher[(5)].

This paper presents an overview of the thin film

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structure and magnetic characteristics obtained for $L1_1$ type Co-Pt ordered alloy film, and describes the results of substitution with a third element for use in practical applications.

2. Structure and Magnetic Characteristics

2.1 Structure of $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film

Fig. 2 shows X-ray diffraction patterns of $Co_{50}Pt_{50}$ ordered alloy film formed by sputtering on Pt seed layers on top of an MgO (111) substrate and a glass disk substrate. In both cases, the diffraction lines were observed from the close-packed plane only, indicating that the benefit of the $L1_1$ type was ensured, i.e., that the close-packed plane is oriented in parallel to the film surface. Additionally, $L1_1$ (111) plane and $L1_1$ (333) plane diffraction lines resulting from the ordered structure of the $L1_1$ type were observed, confirming the $L1_1$ type crystalline structure of the thin film that was formed.

Fig. 3 shows bright field image of a cross-section of the $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film observed by an electron microscope and electronic diffraction lines of the same region, which is formed by sputtering on a Pt seed layer on top of an MgO (111) substrate. The atomic plane from the Pt underlayer to the $Co_{50}Pt_{50}$ film is formed continuously, showing that a single crystal film is composed by looking the diffraction image.

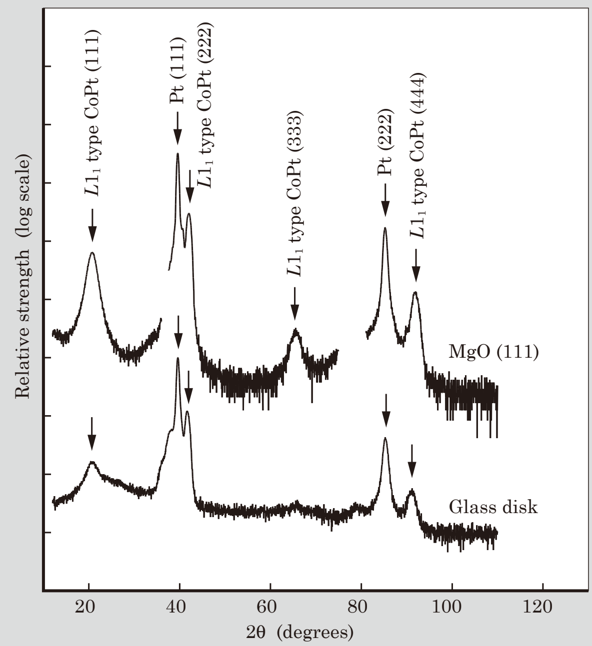

Fig.2 X-ray diffraction patterns of $Co_{50}Pt_{50}$ ordered alloy film formed by sputtering on Pt seed layers on top of an MgO (111) substrate and a glass disk substrate

2.2 Magnetic characteristics of $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film

Fig. 4 shows the relationships between the K_u value and the degree of order S (percentage of ordered structure that has been formed) for $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film and m-$D0_{19}$ type $Co_{80}Pt_{20}$ ordered alloy film. As a reference, the results for $L1_0$ type $Fe_{50}Pt_{50}$ are also shown in the figure.

$L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film, despite having a smaller S value than $L1_0$ type $Fe_{50}Pt_{50}$ ordered alloy film, has a K_u value in the order of 10^7 erg/cm^3 and is comparable to that of $L1_0$ type $Fe_{50}Pt_{50}$. Moreover, the K_u value tends to increase rapidly with increasing S, suggesting that the K_u value of $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film may exceed that of $L1_0$ type

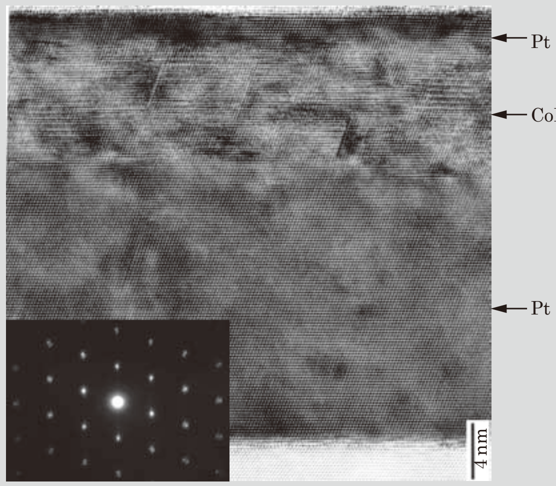

Fig.3 Bright field image of a cross-section of the $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film observed by an electron microscope and electronic diffraction lines of the same region

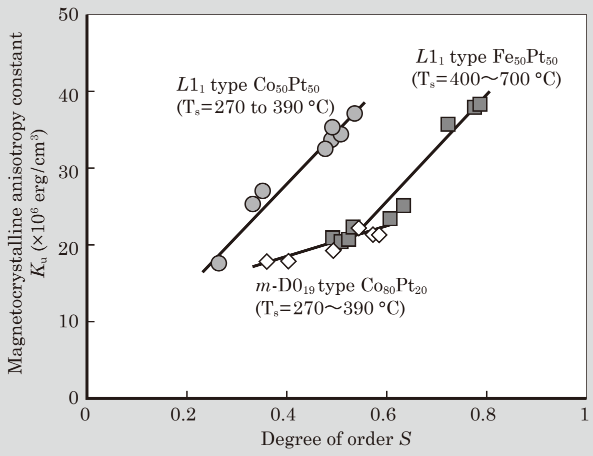

Fig.4 Relationship between K_u and S values of $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film and m-$D0_{19}$ type $Co_{80}Pt_{20}$ ordered alloy film

$Fe_{50}Pt_{50}$ ordered alloy film. If $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film having an S value close to the value 1 can be formed, its K_u value is predicted theoretically to be extremely large[6], and this is supported by experimental results.

From a review of the above findings, $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film was confirmed to be a promising material that has the potential to realize a high K_u value as required for higher densities.

3. Control of Magnetic Characteristics by Substitution With a 3rd Element

3.1 $L1_1$ type $(Co_{1-X}Ni_X)_{50}Pt_{50}$ ordered alloy film

When focusing on applications to actual magnetic recording media, a laminated stack structure consisting of a layer with large magnetic anisotropy (hard layer) and a layer with small magnetic anisotropy (soft layer) is often considered for use as the structure of the recording layer. In this case, the saturation magnetization M_s of the hard layer is in the range of 300 to 700 emu/cm^3, indicating that practical thermal stability can be ensured. Consequently, if $L1_1$ type Co-Pt ordered alloy film will be used as the hard layer in a hard/soft stack structure of the future, the M_s value of $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film will be approximately 1,000 emu/cm^3. To limit this M_s value to the practical level of 300 to 700 emu/cm^3, the development of a method for controlling M_s is needed while maintaining a high K_u value.

This section describes $L1_1$ type (Co-Ni)-Pt ordered alloy film in which Ni has been substituted for a portion of the Co content in $L1_1$ type Co-Pt ordered alloy film[7].

As a basic experiment, films were deposited on MgO(111) substrates. A Pt seed layers were used for (Co-Ni)-Pt layers, and a protective layer of Pt were deposited on the top of the films. The substrate temperature during deposition of the (Co-Ni)-Pt layer was fixed at 360 °C, which is the temperature at which the S and K_u values of $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film become maximums.

Fig. 5 shows the X-ray diffraction pattern of $(Co_{1-X}Ni_X)_{50}Pt_{50}$ in the case where the Pt composition is fixed at a stoichiometric composition of 50 at% and an X amount of Ni has been substituted for Co. As in the case of the $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film, because only diffraction lines from the close-packed plane were observed, the close-packed plane was considered to be oriented in parallel with the surface of the film for all Ni compositions. Also, as in the case of $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy film, an $L1_1$ (111) plane indicating the formation of a $L1_1$ type ordered structure is observed in the vicinity of 2θ=21°, and therefore, an $L1_1$ type (Co-Ni)-Pt ordered alloy film is understood to have been formed.

Fig. 6 shows the M_s and S values of these thin films with respect to the X amount of Ni. As the X amount of Ni increases, the M_s value decreases monotonically and is zero for the $Ni_{50}Pt_{50}$ composition. On the other hand, the S value remained nearly constant at 0.5, regardless of the X amount of Ni.

3.2 $L1_1$ type Co-Ni-Pt ordered alloy film

In section 3.1, it was shown that M_s can be controlled by substituting Ni for a portion of the Co. However, because M_s can also be controlled by the amount of Pt, thin films were fabricated for various composition ranges of Co, Ni and Pt, and were examined for changes in their characteristics. The results show that the $L1_1$ type ordered alloy can be fabricated in a wide compositional range where Co is less than about 65 at%. Fig. 7 superimposes S values of the fab-

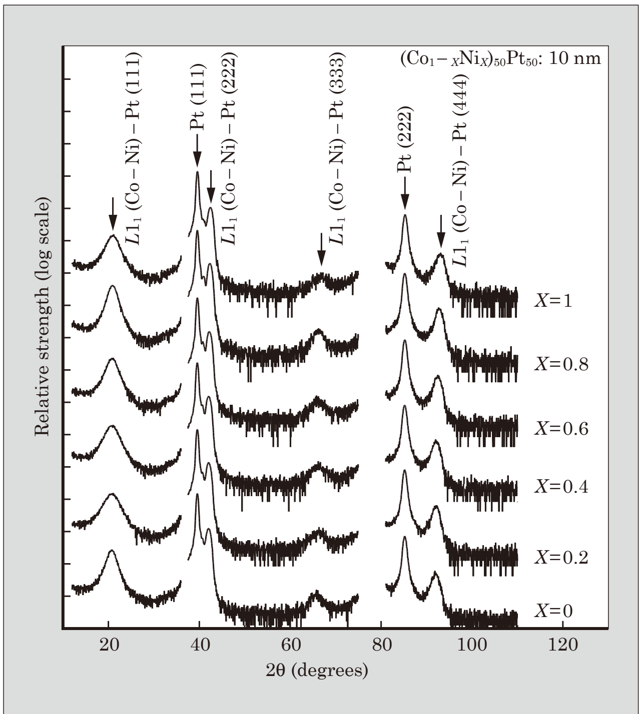

Fig.5 X-ray diffraction pattern of $L1_1$ type $(Co_{1-X}Ni_X)_{50}Pt_{50}$ ordered alloy film

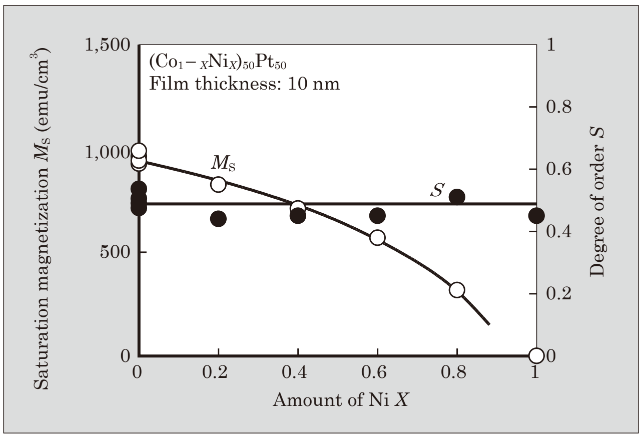

Fig.6 M_s and S values of $L1_1$ type $(Co_{1-X}Ni_X)_{50}Pt_{50}$ ordered alloy film

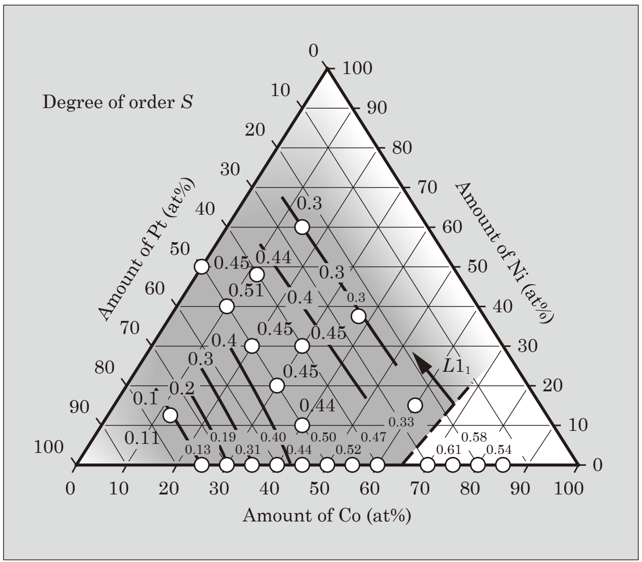

Fig.7 S values of $L1_1$ type Co-Ni-Pt ordered alloy film

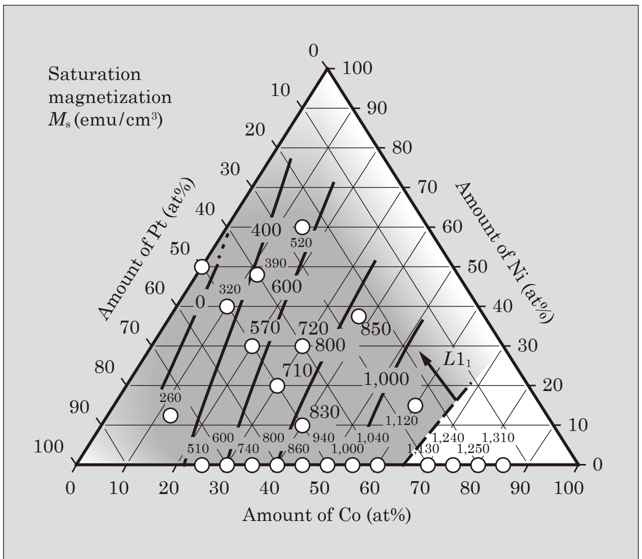

Fig.8 M_s values of $L1_1$ type Co-Ni-Pt ordered alloy film

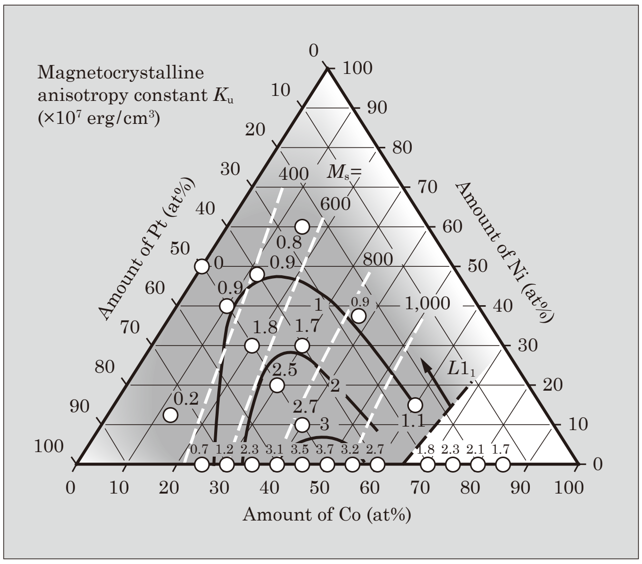

Fig.9 K_u values of $L1_1$ type Co-Ni-Pt ordered alloy film

Table 1 M_s, K_u and S values of representative compositions of $L1_1$ type Co- Pt binary alloys and Co-Ni-Pt ternary alloys

Composition (at%)			Saturation magnetization (emu/cm³)	Magnetocrystalline anisotropy constant (×10⁷ erg/cm³)	K_u/M_s (kOe)	Degree of order S
Co	Ni	Pt				
50	0	50	940	3.7	39.4	0.5
30	0	70	600	1.2	20.0	0.19
25	0	75	500	0.7	14.0	0.13
20	30	50	570	1.8	31.6	0.45
15	60	25	520	0.8	15.4	0.3

ricated thin film on a ternary composition diagram. The bottom line of the triangle shows the dependence of the $L1_1$ type Co-Pt ordered alloy on the Pt compositional amount. Looking at the S isolines, the degree of order can be seen to be a maximum in the vicinity of the stoichiometric composition of the aforementioned $(Co_{1-X}Ni_X)_{50}Pt_{50}$ (line from the $Co_{50}Pt_{50}$ point toward the $Ni_{50}Pt_{50}$ point). Furthermore, because the S isolines runs parallel to the Pt composition isolines, the S value can be seen as being determined primarily by the Pt composition. When the Co composition is greater than about 65 at%, m-$D0_{19}$ is formed and the dotted line in the figure indicates the m-$D0_{19}$ phase boundary.

Fig. 8 shows the value of M_s in the same format as that of S shown above. M_s decreases monotonically as the Co composition decreases (Ni composition increases), indicating that M_s can be controlled by the composition.

Fig. 9 similarly shows the value of K_u. The M_s isolines are also shown in the figure. The absolute value K_u, as in the case of S, becomes a maximum for the $(Co_{1-X}Ni_X)_{50}Pt_{50}$ composition. On the other hand, in regions displaced away from the stoichiometric composition, the absolute value of K_u can be seen to decrease gradually when the Pt composition is lower, rather than higher. This finding is qualitatively consistent with the results for S.

Table 1 lists representative $L1_1$ type Co-Pt binary alloys and Co-Ni-Pt ternary alloys capable of realizing M_s values in the range of 500 to 600 emu/cm³, which is suitable for practical applications. When the M_s value is set to approximately 600 emu/cm³, the K_u value of the binary alloy drops to 1.2×10^7 erg/cm³. On the other hand, in the case where Ni is substituted to reduce the M_s value, an extremely high K_u value of 1.8×10^7 erg/cm³ is found to be maintained. Moreover, when the M_s value is set to approximately 500 emu/cm³, the magnetic characteristics are about the same for both binary and ternary alloys, but a comparison of the amounts of Pt shows that the required amount of Pt has decreased by one-third from 75 at% for the binary alloy to 25 at% for the ternary alloy. That is, the Co-Ni-Pt ternary alloy can realize the same or better magnetic characteristics as the Co-Pt binary alloy, but with a lower Pt composition.

This section has described the $L1_1$ type Co-Ni-Pt ordered alloy film for which the M_s value can be controlled while maintaining a high K_u value. The Co-Ni-Pt ternary alloy forms $L1_1$ type ordered alloy film over a wide compositional range, and in a composition of reduced Pt, which is a rare material, magnetic characteristics that are the same or better than those of the $L1_1$ type Co-Pt ordered alloy film can be realized. This finding indicates that Co-Ni-Pt material is promising as a material for the hard layer in future hard/soft laminated type media.

4. Postscript

If recording densities keep the current pace of increase, the mass-production of magnetic recording media requiring K_u values in the order of about 10^7 erg/cm^3 as exhibited by this material is expected to begin around 2013. For this purpose, Fuji Electric will continue to address future challenges with a sense of urgency.

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