INTRODUCTION

Among the various binary alloys, Fe₃Pt alloys are interesting alloy to study because of its interesting behavior and properties. The Fe₃Pt alloy was reported to exhibit the so-called invar properties of anomalous thermal expansion coefficients and the large magneto-volume effect¹. The compounds close to Fe₃Pt displayed unusually sharp ferromagnetic anomalies in the thermal expansion coefficient and strong magnetostrictive properties². Giant magnetostriction was observed in an ordered Fe₃Pt single crystal³. The Curie temperature of Fe₃Pt was reported to be sensitive to pressure. The previous experimental observation suggested that the pressure caused to change the degree of ordering and thus the Curie temperature⁴. It was reported that exchange coupled nano-composite magnets made from Fe₃Pt and FePt showed large energy product, which exceeded the theoretical limit for non-exchange-coupled Fe₃Pt alloy thin films⁵. Theoretical band structure calculations on ordered Fe₃Pt revealed strong hybridization between Fe and Pt d-states and a resultant unusually high density of states (DOS) at the Fermi level compared to other strong ferromagnets such as Fe⁶-⁸. Large cubic magnetic anisotropy was observed in Fe₃Pt thin films at room temperature⁹. Double switching hysteresis curve were obtained in Fe₃Pt alloy thin films¹⁰,¹¹. Due to these many interesting phenomena, Fe₃Pt has been the focus of study by many researchers. In spite of these extensive works carried out, there are very few works focusing on the temperature dependent magnetic properties especially magnetic anisotropy of Fe₃Pt thin films. This breeds the scientific curiosity to investigate its nature and origin. Therefore, the temperature dependent magnetic properties of Fe₃Pt thin films were studied in this manuscript.

EXPERIMENTAL

The Fe₃Pt thin films were fabricated by electron beam evaporation onto MgO(100) and MgO(111) substrates using Fe and Pt separate targets in a vacuum better than 10⁻⁷ Torr. The substrate deposition temperature (Tₛ) was varied from ambient to 550°C. The combined deposition rate was 0.7Å/sec and thickness of the samples
was about 50nm. The samples were rotated in order to get the better uniformity of thickness. Film stoichiometry was achieved by controlling the deposition rate of individual elements, Fe ($\gamma$$_{Fe}$=0.47Å/sec) and Pt ($\gamma$$_{Pt}$ =0.23Å/sec). All the films were analyzed by the Energy Dispersive X-ray diffraction and the film compositions were found within the range of ±1% from the stoichiometric composition. The in-plane magnetic anisotropy of Fe$_3$Pt alloy thin films were measured by in-plane torque measurements. The entire samples were made circular in shape in order to avoid the shape magnetic anisotropy. The magnetic anisotropy constants, $K_1$ of Fe$_3$Pt films were obtained from the $<$001$>$ oriented samples grown onto MgO(100) substrate while the magnetic anisotropy constants $K_2$ were obtained from the $<$111$>$ oriented samples grown onto MgO(111) substrate. The torque measurements were carried out in the temperature range ($T$) of 80K to 600K. The Curie temperature ($T_C$) of the samples was determined from the temperature dependent magnetization curve.

### RESULTS AND DISCUSSIONS

In our earlier paper, we demonstrated the close relationship of magnetic anisotropy constants of Fe$_3$Pt thin films with the structural parameter [9, 12]. The Fe$_3$Pt films grown at 400°C were partially ordered and exhibited maximum magnetic anisotropy at room temperature as reported earlier [9]. In this paper, the temperature dependent magnetic properties such as saturation magnetization, coercivity, magnetic anisotropy constant etc. of Fe$_3$Pt thin films were studied. Measurements were carried out in the range from 80K to 600K. Fig. 1 shows the temperature dependence of saturation magnetization ($M_s$). At 80K, the saturation magnetization, $M_s$ was about 1300 emu/cc and diminished at about 625K. The coercivity ($H_C$) of Fe$_3$Pt alloy thin films as a function of temperature was depicted in fig. 2. The maximum coercivity was obtained at 80K of about 2 KOe. The magnetization and the coercivity fell in similar fashion with the temperature.

The Curie temperature was determined from the inflection point of $M$ vs. $1/T$ plot. The Curie temperature, $T_C$ for the partially ordered ($S$=0.3) case was found about 625K (352°C). The result of $T_C$ as a function of the ordering parameter, $S$ is shown in Fig. 3. The ordering parameter was estimated according to ref. [9]. It was observed that the Curie temperature decreased with the degree of ordering, although, there was a scatter in the data at $S$=0. The reason of this decrement of $T_C$ with the ordering was not clearly understood. However, the nearest neighbor occupancy probabilities and the change of atomic interactions from disordered to ordered state [13] or the pair-
ordering mechanism might be the origin of the change in Curie temperature. It is known that pair-ordering originates from the unbalanced distribution of the atoms [14, 15]. In Fe₃Pt alloy, three kinds of atomic pairs are possible such as Fe-Fe, Fe-Pt or Pt-Pt. As only Fe is magnetic, the interaction energy (dipolar and quadrapolar) is believed to depend mainly on the number of Fe-Fe pairs. The numbers of pairs depend on the order parameter that is controlled by growth temperature. The number of Fe-Fe planer pairs in Fe₃Pt alloy is found to decrease with the ordering by simple calculations [12], which might be related with this decrement of the Curie temperature in the present case. The Curie temperature for the highest ordered sample ($S=0.67$) was obtained of about 513K (240°C), a little bit larger than that (435K, 162°C) for the bulk ordered Fe₃Pt.

![Fig. 3: The Curie temperature, $T_c$ of Fe₃Pt alloy thin films grown onto MgO(100) substrate as a function of ordering parameter, $S$](image)

![Fig. 4: The variation of magnetic anisotropy constant, $K_1$ and $K_2$ as a function of measurement temperature ($T$) of the Fe₃Pt alloy thin films grown onto MgO substrates](image)

![Fig. 5: The temperature dependence of normalized magnetic anisotropy constant, $K_1$ of Fe₃Pt films. (The solid line is a measured value while the dashed line is a fitted curve from the magnetization)](image)
The temperature ($T$) dependence of $K_1$ and $K_2$ of Fe$_3$Pt thin films grown at 400ºC were investigated over a range from 80K to 600K. The 4-fold and 6-fold symmetry torque curves were observed over the entire temperature range for the two-oriented samples grown on MgO substrates. However, a change in the torque amplitude was noticed with temperature. The magnetic anisotropy constants, $K_1$ and $K_2$ were found to decrease with the increasing $T$ as shown in Fig. 4. When the measurement temperature approached towards the Curie temperature (measured value of Curie temperature of the Fe$_3$Pt film was about 600K), both the magnetic anisotropy constants $K_1$ and $K_2$ gradually vanished similar to other ferromagnetic material. According to the previous theory, the power law dependence of magnetization can be expressed as \[ K_1(T)/K_1(0)=M(T)/M(0)^n \] where $M(0)$ and $M(T)$ are the magnetization at temperature 0K and $T$. We employed $K_1(T)/K_1(80K)=M(T)/M(80K)^n$ and numerically fitted our data. From the best fitted value as shown in fig.5, the exponent, $n=1.3$ was obtained. This value of $n$ was smaller as predicted by Zener and Carr. According to those theories, the value of $n$ would be 3 and 10 for uniaxial and cubic cases respectively. This kind of unexpected dependence of magnetic anisotropy was also observed in other materials. Further theoretical framework is necessary to explain this behavior. However, from the nature of the slow decrement, one can say that the magnetic anisotropy energy of Fe$_3$Pt films is more stable than other transition metal alloys in a wide range of temperature.

CONCLUSIONS

In this manuscript, the temperature dependent magnetic properties of the Fe$_3$Pt thin films grown on MgO substrates were studied in the temperature range varying from 80K to 600K. At 80K, the saturation magnetization ($M_s$) and coercivity ($H_c$) of Fe$_3$Pt films (grown at 400ºC) were obtained about 1300 emu/cc and 2000 Oe. Both $M_s$ and $H_c$ dropped in similar fashion with temperature. The Curie temperature of Fe$_3$Pt films as a function of ordering was investigated and it was found to decrease with the ordering. The reason was yet to be cleared up. However, we believe that the pair ordering mechanism might be the origin of this decrement. The important result was in the case of magnetic anisotropy. The Fe$_3$Pt films (grown at 400ºC) at 80K possessed a very large magnetic anisotropy constant. The in-plane magnetic anisotropy constants, $K_1$ and $K_2$ obtained were about $-7\times10^6$erg/cc and $2.2\times10^7$erg/cc respectively. The in-plane magnetic anisotropy constants of Fe$_3$Pt films at lower temperature (80K) were little bit larger in compare to the room temperature values. Both the magnetic anisotropy constants of Fe$_3$Pt thin films dropped with temperature with the 1.3 power of magnetization. It was relatively slower rate in the case of cubic magnetic anisotropy as predicted by the theory. Thus, the magnetic anisotropy constants were found stable in a wide range of temperature.

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