Comparative Study of Magnetic and Electrical Behavior of Titanium-Niobium Alloy Thin Films Prepared by RF-Magnetron Sputtering Method

ADITI[1] ANAND K. TYAGI[2]

[1]Department of Applied Sciences, I. K. Gujral Punjab Technical University, Jalandhar (Punjab), India.
[2]Department of Applied Sciences, SBS State Technical Camus, Firozpur (Punjab), India
aditigoyal2210@gmail.com, anandktyagi@gmail.com

***ADITI,** [1]Department of Applied Sciences, I. K. Gujral Punjab Technical University, Jalandhar (Punjab), India. aditigoyal2210@gmail.com

Abstract: *- This research paper reports on combined magnetic and electrical properties of $Ti_{1-x}Nb_x$ ($0.0<x\leq0.5$) alloy thin films with x= 0.1, 0.2, 0.3, 0.4 and 0.5 (i.e. 10, 20, 30, 40 and 50 %) atomic weight grown on glass substrate by using RF Magnetron sputtering method. We have used three substrate temperature variations (100°C, 200°C and 300°C) for these five alloy thin film samples. The Magnetic hysteresis (M-H) behavior of $Ti_{1-x}Nb_x$ alloy thin films was observed at room temperature by using VSM with the applied magnetic field of ± 2 Tesla. VSM results reveal that with increase in niobium content from 10% to 50% of alloy, there is no clear trend in pattern of magnetization of the $Ti_{1-x}Nb_x$ alloys across all temperature variations (100°C, 200°C and 300°C). VSM result shows the paramagnetic behavior for majority of samples at room temperature and some of the $Ti_{1-x}Nb_x$ alloy thin films changed from paramagnetic to ferromagnetic-like properties. This interesting evolution of magnetic properties of $Ti_{1-x}Nb_x$ thin alloys evokes new understanding of these alloy thin films. The electrical resistivity of the films as a function of $Ti_{1-x}Nb_x$ alloy and temperature variation were studied by Hall Measurements. Resistivity of thin films samples decreases with increase in niobium content for all substrate temperature at 100°C, 200°C and 300°C.*

Keywords: $Ti_{1-x}Nb_x$ alloy, RF Magnetron Sputtering, Magnetic Properties, VSM and Hall Measurements

INRTODUCTION

Both VSM and Hall Effect measurements have been valuable tools for analyzing the material characterization for Titanium and its alloys for a wide range of industries like optoelectronics, catalysis, medicine, sensor devices, photonic crystal and microelectronic devices [1-7]. According to earlier research studies, it seems that titanium does have magnetic properties however they are very weak especially when we compare them to the ferromagnetic materials [8, 9]. Due to this reason there has not been many studies related to magnetic properties of Titanium and its alloys. Magnetic properties of Titanium can be improved by making it alloy with other elements. Since titanium has got some magnetic field, it is easy to boost these properties when it is mixed with magnetic metal and it may provide useful results for

industry. Also, electrical properties of Titanium can be improved with alloying metals like Vanadium, Niobium etc for new application in areas like manufacture of solar cells on dyes, catalysts and others. Considering the fact that magnetic and electrical properties of Titanium-Niobium alloys has not been discussed in past, in the present research work, a systematic procedure was adapted in the preparation of the $Ti_{i-x}Nb_x$ alloy thin films with x= 0.1, 0.2, 0.3, 0.4 and 0.5 (i.e. 10, 20, 30, 40 and 50 % atomic weight) using RF magnetron sputtering technique in the temperature range of 100°C to 300°C and to characterize them mainly for their magnetic and electrical properties by using VSM and HALL Measurements.

EXPERIMENT DETAILS

Deposition: - In this research experiment Ti-Nb alloy thin films were prepared by using RF magnetron sputtering method. We have used 5 targets of composition Ti90Nb10 (82.3 wt.% Ti-16.7wt.%Nb), Ti80Nb20(67 wt.% Ti-33wt.%Nb), Ti70Nb30(55 wt.% Ti-45wt.%Nb), Ti60Nb40 (44 wt.% Ti-56wt.%Nb) and Ti50Nb50 (34 wt.% Ti-66wt.%Nb). $Ti_{i-x}Nb_x$ alloy targets have diameter of 50-mm and thickness about 3-mm. These alloy targets have around 99.9% purity. We have used glass as substrate on which Ti-Nb alloy thin films was deposited. The glass substrates were cleaned thoroughly with acetone and then dried with dry air. As per requirement of sample size, glass substrates were cut and fasten on substrate holder. Substrate holder was fixed in the sputtering chamber. Inside the sputtering chamber, vacuum was created by turbo molecular pump. Vacuum was not less than 10^{-6} Torr during research experiment. For sputtering gas, 99.9% pure argon (Ar) gas was inserted and gas flow rate of argon was kept constant at 15 sccm. Base pressure and working pressure were kept at $8x10^{-6}$ mbar and at 1.7 x 10^{-2} mbar respectively. In the sputtering chamber target-substrate distance was around 10 cm. During experiment sputtering RF power was kept at 100W and substrate temperature was variable at 100°C, 200°C and 300°C. Thickness of film was kept constant at 200 nm.

RESULTS AND DISCUSSIONS

Vibrator Sample Magnetometer (VSM): -

Material which shows magnetic response when placed in a magnetic field is broadly classified into five categories namely ferromagnetic, paramagnetic, diamagnetic, antiferromagnetic, and ferrimagnetic materials. Titanium is paramagnetic in character;

niobium is also having paramagnetic properties [10-13].The alloys of $Ti_{1-x}Nb_x$ have been deposited in the form of thin films. Magnetization measurements have been performed for all Ti-Nb alloy samples prepared under different compositions ($Ti_{1-x}Nb_x$) and temperature variation (100°C, 200°C and 300°C). The temperatures variation and different alloy compositions are primary factors in distinguishing their magnetic behaviors. The VSM images in Fig-1, Fig-2 and Fig-3 respectively depict the magnetization of Ti-Nb alloy films for all five samples at different temperatures of 100°C, 200°C and 300°C. Magnetization hysteresis loops measured in the field range between +2 Tesla to -2 Tesla.

At 100°C, from Table -1, it can be seen that magnetic properties like Magnetization, coercivity and Retentivity do not show any particular behavior and pattern with increase in Niobium content from (10% to 50%) in $Ti_{1-x}Nb_x$ alloy. Magnetization of samples Ti80Nb20, Ti70Nb30 and Ti60Nb40 were higher than other two samples. Retentivity is higher for samples Ti80Nb20 and Ti70Nb30. From the fig-1, hysteresis loop of all five samples at 100°C are recorded. In fig-1(a) hysteresis loop does not show any pattern for sample Ti90Nb10. In fig-1(b) and fig-1(c), thin film samples of Ti80Nb20 and Ti70Nb30 show paramagnetic behavior with little kink in curve. Fig-1(d) does not show any particular pattern for sample Ti60Nb40. Fig-1(e) clearly displays the paramagnetic behavior of the sample Ti50Nb50. We can conclude that for 100°C, mostly samples behave in paramagnetic properties. The hysteresis loop also indicated the weak magnetic properties in sample.

Table: - 1 Magnetization, Coercivity and Retentivity of $Ti_{1-x}Nb_x$ alloy at 100°C

Targets	**Magnetization (emu)**	**coercivity(G)**	**Retentivity (emu)**
Ti90Nb10	159.12×10^{-6}	97.147	4.31×10^{-6}
Ti80Nb20	348.69×10^{-6}	282.66	30.08×10^{-6}
Ti70Nb30	269.68×10^{-6}	192.46	22.20×10^{-6}
Ti60Nb40	340.76×10^{-6}	1560.8	2.09×10^{-6}
Ti50Nb50	184.22×10^{-6}	10.852	1.15×10^{-6}

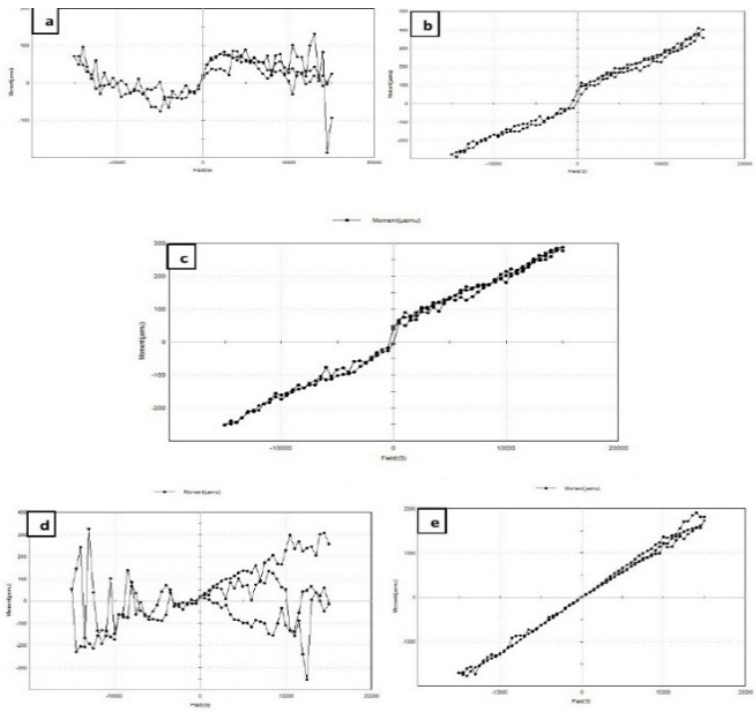

Fig 1. VSM graphs of $Ti_{1-x}Nb_x$ alloy thin films at different compositions at 100°C

At 200°C, from Table-2, it can be seen that magnetic properties like Magnetization, coercivity and Retentivity show similar behavior and pattern with increase in Niobium content from (10% to 50%) in $Ti_{1-x}Nb_x$ alloy. Magnetization for all samples are in similar range from 101.7x 10^{-6} to 211.3x10^{-6}. Retentivity and coercivity of all the samples are in similar range except for one sample Ti90Nb10. From the fig-2, hysteresis loop of all five samples at 200°C are recorded. In all the five samples from Fig- 2(a) to 2(e) paramagnetic properties are dominant and clearly show that all samples are paramagnetic in nature.

Table: - 2 Magnetization, Coercivity and Retentivity of $Ti_{1-x}Nb_x$ alloy at 200°C

Targets	**Magnetization(emu)**	**Coercivity**	**Retentivity**
Ti90Nb10	101.7x 10^{-6}	39.36	4.08x10^{-6}
Ti80Nb20	197.8x10^{-6}	46.58	6.50x10^{-6}
Ti70Nb30	206.5x10^{-6}	53.21	7.61x10^{-6}
Ti60Nb40	139.8x10^{-6}	44.22	5.81x10^{-6}
Ti50Nb50	211.3x10^{-6}	45.16	8.82x10^{-6}

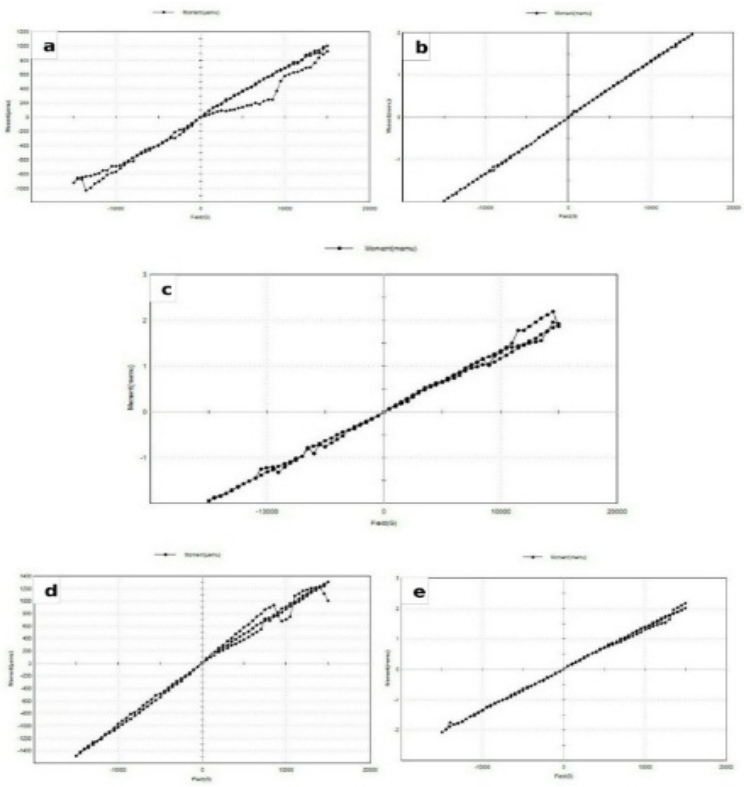

Fig 2. VSM graphs of $Ti_{1-x}Nb_x$ alloy thin films at different compositions at 200°C

At 300°C, from Table-3, it can be seen that magnetic properties like Magnetization, coercivity and Retentivity do not show any particular behavior and pattern with increase in Niobium content from (10% to 50%) in $Ti_{1-x}Nb_x$ alloy. Magnetization of samples Ti80Nb20 andTi50Nb50 are substantially higher than other three samples of Ti90Nb10, Ti70Nb30 and Ti60Nb40. Retentivity is higher for samples Ti70Nb30 and Ti60Nb40. From the fig-3, hysteresis loop of all five samples at 300°C are recorded. In fig-1(a) hysteresis loop does not show any pattern for sample Ti90Nb10. In fig-3(b) thin film sample of Ti80Nb20 show paramagnetic behavior. Fig-3(c) and 3(d) show ferromagnetic-like patterns for sample Ti70Nb30 and Ti60Nb40. Fig-1(e) clearly displays the paramagnetic behavior of the sample Ti50Nb50. We can conclude that for 300°C, two samples Ti80Nb20 and Ti50Nb50 behave in paramagnetic patterns and two samples Ti70Nb30 and Ti60Nb40 behave in ferromagnetic-like patterns.

Table: - 3 Magnetization, Coercivity and Retentivity of $Ti_{1-x}Nb_x$ alloy at 300°C

Targets	**Magnetization(emu)**	**Coercivity**	**Retentivity**
Ti90Nb10	78.02x 10^{-6}	46.43	13.19x10^{-6}

Ti80Nb20	404.06×10^{-6}	289.19	13.47×10^{-6}
Ti70Nb30	119.63×10^{-6}	184.50	38.16×10^{-6}
Ti60Nb40	110.44×10^{-6}	6112.3	44.59×10^{-6}
Ti50Nb50	311.15×10^{-6}	383.54	9.89×10^{-6}

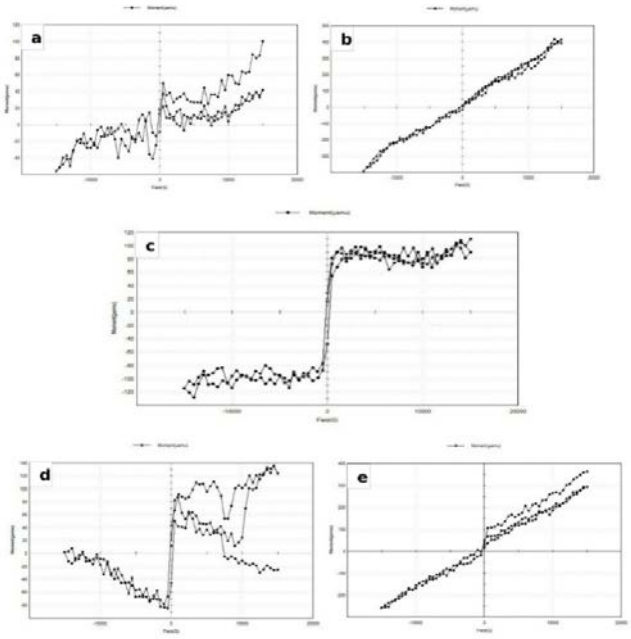

Fig 3. VSM graphs of $Ti_{1-x}Nb_x$ thin films at different compositions at 300°C

When we compare magnetic properties with rise in temperature, it is clear from the fig-4 and fig-5 that magnetization is higher at Ti80Nb20 for 300°C, Ti80Nb20 and Ti60Nb40 for 100°C.There is increase in Retentivity with rise in temperature. Retentivity is much higher for samples Ti70Nb30 and Ti60Nb40 at 300°C.

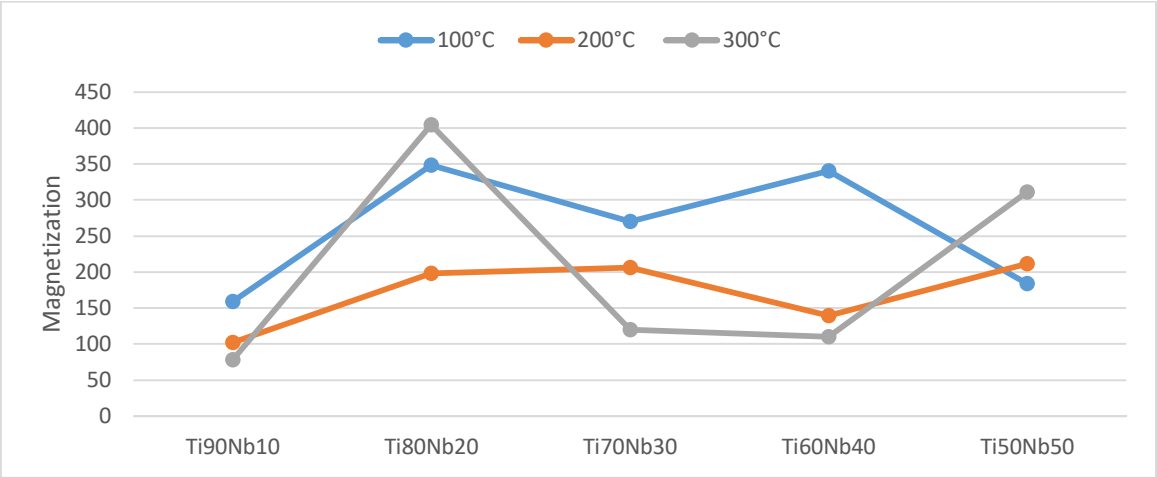

Fig 4. Comparison of magnetization of $Ti_{1-x}Nb_x$ thin films at 100°C, 200°C and 300°C

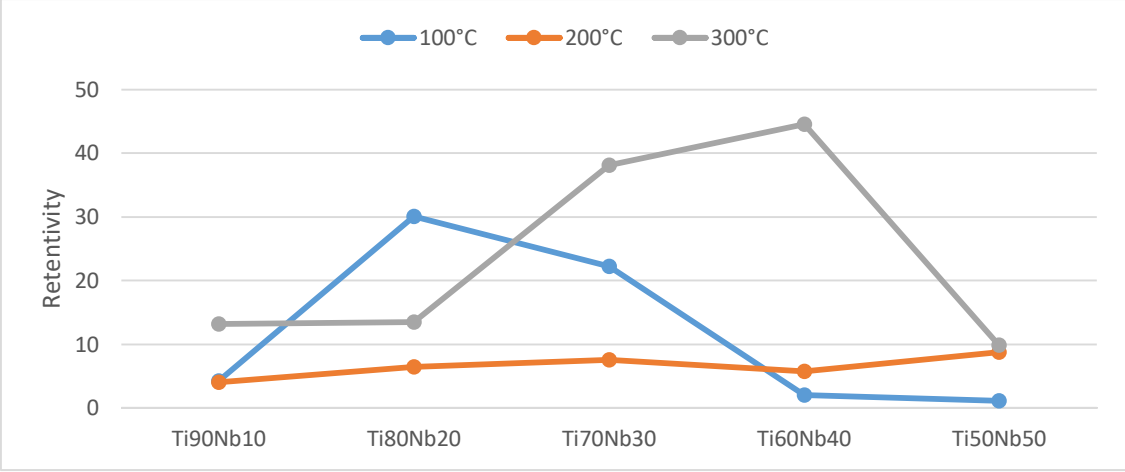

Fig 5. Comparison of Retentivity of $Ti_{1-x}Nb_x$ thin films at 100°C, 200°C and 300°C

Hall Effect Measurements:-

In this research paper, the change in the electrical resistivity of the $Ti_{1-x}Nb_x$ (x = 10, 20, 30, 40 and 50 at %) films could be mainly attributed to the difference in composition with increased niobium, temperature variation and microstructural evolution. Niobium ion has ion radius close to titanium ions and so it is easily built into lattice. Five alloy thin films $Ti_{1-x}Nb_x$ (x = 10, 20, 30, 40 and 50 at %) deposited at 100°C, 200°C and 300°C respectively. At 100°C, when we increase niobium content in alloy from 10 %(Ti90Nb10) to 50% (Ti50Nb50) resistivity decreases from 7.30 $x10^{-4}\Omega$-m to 2.39 $x10^{-4}\Omega$-m (Table no-4). At 200°C, when we increase niobium content in alloy from 10 %(Ti90Nb10) to 50 %(Ti50Nb50) resistivity decreases from $7.07x10^{-4}$ Ω-mto 3.51 $10^{-4}\Omega$-m (Table no-5). At 300°C, when we increase niobium content in alloy from 10% (Ti90Nb10) to 50% (Ti50Nb50) resistivity decreases from 8.63 $x10^{-4}\Omega$-m to 3.99 $x10^{-4}\Omega$-m (Table no-6). From the results we can conclude that resistivity of Ti-Nb alloy thin films are sensitive to the niobium content and substrate temperature. Resistivity tends to decrease with increase in niobium content at all the temperature variants with exception Ti-40%Nb.

Table: -4 Resistivity of $Ti_{1-x}Nb_x$ alloy at 100°C

Temprature	**Nb content in $Ti_{1-x}Nb_x$ alloy (in percentage)**	**Resistivity($x10^{-4}$) (Ω-m)**
100°C	10	7.30
100°C	20	5.28
100°C	30	4.31
100°C	40	8.23

100°C	50	2.39

Table: -5 Resistivity of $Ti_{1-x}Nb_x$ alloy at 200°C

Temprature	**Nb content in $Ti_{1-x}Nb_x$ alloy (in percentage)**	**Resistivity($x10^{-4}$) (Ω-m)**
200°C	10	7.07
200°C	20	4.58
200°C	30	2.85
200°C	40	11.3
200°C	50	3.51

Table: - 6 Resistivity of $Ti_{1-x}Nb_x$ alloy at 300°C

Temprature	**Nb content in $Ti_{1-x}Nb_x$ alloy (in percentage)**	**Resistivity($x10^{-4}$) (Ω-m)**
300°C	10	8.63
300°C	20	8.07
300°C	30	7.46
300°C	40	11.1
300°C	50	3.99

If we compare resistivity of thin films across temperature variants 100°C, 200°C and 300°C (fig-6), it can be clearly seen the similar trends of resistivity. Resistivity of Ti-Nb thin films increases with increase in temperature which is clearly formulated in fig 6.

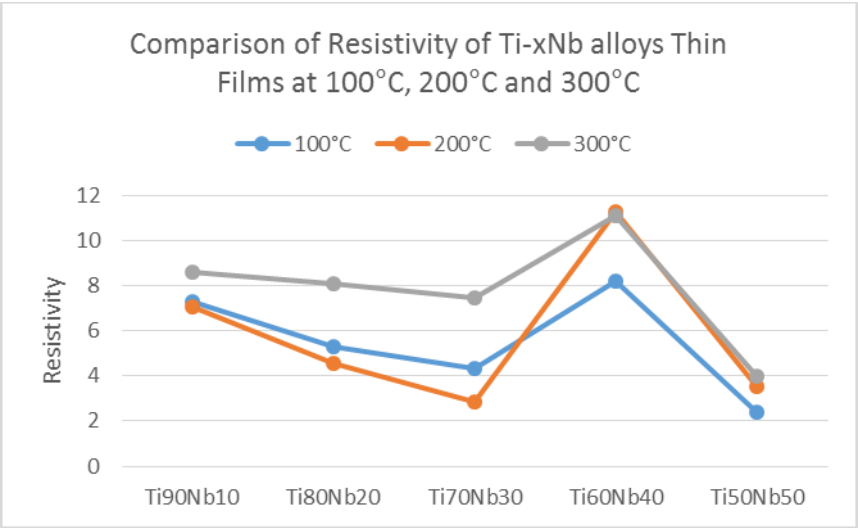

Fig 6. Comparison of Resistivityof Ti-Nb alloy thin films at 100°C, 200°C and 300°C

CONCLUSIONS

Five samples of fine grained ($Ti_{1-x}Nb_x$) alloys thin films with nominal compositions of $Ti_{1-x}Nb_x$ with x= 0.1, 0.2, 0.3, 0.4 and 0.5 (i.e. 10, 20, 30, 40 and 50 % atomic weight) were successfully prepared on glass substrate at different substrate temperature (100°C, 200°C and 300°C) by RF magnetron sputtering technique. Magnetic and electrical properties of these thin films were investigated by VSM and Hall Measurements. Experimental results indicated that magnetic and electrical properties of Ti-Nb alloys are sensitive to Nb content and temperature variation.VSM characterization indicated that with increase in Niobium content from 10% to 50%, magnetization does not follow any particular trends in all the temperature variations of 100°C, 200°C and 300°C. At 100°C, magnetization is higher for Ti80Nb20 and Ti60Nb40 with 348.69×10^{-6}emu and 340.76×10^{-6}emu. Retentivity is higher for sample Ti80Nb20. Most of 5 samples show paramagnetic properties in hysteresis loop. At 200°C magnetization for all samples remains same in range from 101.7×10^{-6}emu to 211.3×10^{-6} emu and show paramagnetic properties for all samples. At 300°C, magnetization increases from 78.02×10^{-6}emu to 311.15×10^{-6}emu from sample Ti90Nb10 to Ti50Nb50. However for sample Ti80Nb20, magnetization is highest with value 404.06×10^{-6}emu. Two samples Ti80Nb20 and Ti50Nb50 behave in paramagnetic patterns and two samples Ti70Nb30 and Ti60Nb40 behave in ferromagnetic-like patterns. Hall effects measurements showed a characteristic trend of variation in electrical properties of the films; electrical resistivities of the thin films are found to decrease with the increase niobium content in all three temperature variations. For 100°C, resistivity decreases from 7.30×10^{-4} Ω-m to 2.39×10^{-4}Ω-m, for 200°C, resistivity decreases from 7.07×10^{-4} Ω-m to $3.51\ 10^{-4}$ Ω-m and for 300°C, resistivity decreases from 8.63×10^{-4} Ω-m to 3.99×10^{-4} Ω-m.

CONFLICT OF INTEREST: None

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