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Novel Co_2Mn-Based Heusler Alloy Microwires with Promising Magnetization Thermal Stability for Multifunctional Applications

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Abstract: In current work, we illustrate the effect of adding small amount of Carbon to very common Co_2MnSi Heusler alloy based-glass coated microwires. A significant change in the magnetic and structure structural properties has observed for the new alloy Co_2MnSiC compared to the Co_2MnSi alloy. The magneto-structural investigations have performed to clarify the main physical parameters i.e., structural & magnetic at a wide range of measuring temperature. The XRD analysis illustrated the well-defined crystalline structure with average grain size (D_g = 29.16 nm) and a uniform cubic structure with A2-type compared to the mixed $L2_1$ and B2 cubic structures for Co_2MnSi-based glass coated microwires. The magnetic behaviour has investigated at a temperature range (5 to 300 K) and an external applied magnetic field (50 Oe to 20 kOe). The adding of small amount of Carbon to the Co_2MnSi matrix enhance the magnetic thermal stability, where the thermomagnetic behaviour of Co_2MnSiC glass-coated microwires show a perfect stable behaviour for a temperature range from 300 K to 5 k, the differences between the coercivity value is only 0.3 Oe compared to 4 Oe for Co_2MnSi-sample. In addition, M-H loops measured at temperature below 50 K show unsaturated loops; meanwhile the Co_2MnSi loops shows a strong antiferromagnetic coupling for the loops measured below 50 K. By studying the field cooling (FC) and field heating (FH) magnetizations curves at a wide range of external applied magnetic field we detected a critical magnetic field (H = 1 kOe) where FC and FH curves have a stable magnetic behavior for Co_2MnSiC sample, such stability does not find in Co_2MnSi sample. We proposed a phenomenal expression to estimate the magnetization thermal stability, ΔM (%), of FC and FH magnetization curves and the maximum value is detected at the critical magnetic field where ΔM (%) ≈ 98 %. The promising magnetic stability of Co_2MnSiC glass-coated microwires with temperature is due to the changing of the microstructure induced by adding Carbon, as the A2-type structure show a unique stability by variation the temperature and the external magnetic field. In addition, a unique internal mechanical stress, which induced during the fabrication process and plays on controlling magnetic behavior with temperature and external magnetic field. The obtained results make Co_2MnSiC promising candidate for magnetic sensing devices based Heusler glass-coated microwires.

Keywords: Heusler alloys; glass-coated microwires; thermal stability; magnetic sensing; HR-TEM

1. Introduction

Nano- and Micro- structured magnetic materials offer special physical characteristics that make them suitable in a variety of industrial applications, including information technology, energy, and healthcare. They utilized in the creation of computer memory, MRI machines, spintronic devices, magnetic refrigeration, hard disk drives, magnetic sensors, renewable energy sources, and computer memory [1–4]. Their special qualities make them a fantastic substitute for traditional materials and have the ability to completely transform a variety of sectors by making them more effective, economical, and environmentally friendly.

Magnetic Heusler alloys are a class of materials that have gained significant attention due to their unique magnetic properties [5,6]. These alloys are composed of transition metals such as cobalt, iron, and nickel, and are known for their half-metallic behavior, meaning that they have a high electrical conductivity in one spin channel and a low electrical conductivity in the other [7]. In addition, Heusler alloys can have a high magnetization and a high Curie temperature, making them resistant to demagnetization at high temperatures [8]. These properties make Heusler alloys promising candidates for use in a wide range of applications, including magnetic storage media, sensors, and energy-efficient motors [5,9,10]. However, further research is needed to fully understand these materials' behavior and to optimize their properties for practical use.

Co_2Mn-based Heusler alloys are a type of intermetallic compound that are composed of cobalt, manganese, and a small amount of a third element, such as aluminum or silicon. These alloys are known for their interesting magnetic and electronic properties, which make them of interest for a variety of applications, including in spintronic devices, sensors, and energy-efficient motors [9–11].

One of the most notable properties of Co_2Mn-based Heusler alloys , (especially Co_2MnSi) is that they can exhibit half-metallic behavior, meaning that they have a high density of states at the Fermi level for one spin channel, but not the other [9,12,13]. These alloys are widely recognized for its large bandgap for minority spins (0.5 to 0.8 eV), high Curie temperature (~985 K), high tunnel magnetoresistance, large magnetoresistance ratios and perpendicular magnetic anisotropy [11–14]. Both of the experimental and theoretical investigation conducted on Co_2MnSi in last two decades have focused on the analysis of structural and magnetic properties and their relation to spin polarization [12–15]. The highest value of spin polarization for bulk Co_2MnSi is ~ 93%, was measured at room temperature by ultraviolet-photoemission spectroscopy [15]. These properties are useful for a variety of applications, including in cutting tools and wear-resistant coatings. Co_2Mn-based Heusler alloys can be produced through various methods, including powder metallurgy, spark plasma sintering, and hot isostatic pressing [15]. Doping the alloy with concordant atoms is one of the suitable methods for tuning the bandgap value of Heusler alloys [16]. Therefore, in current study we want to investigate the effect of adding Carbon to the Co_2MnSi alloy on the magneto-structural properties. Carbon addition, used to improve phase stability and coercivity, leads to the deformation of the unit cell and can affect the Mn-Mn coupling [17,18]. Thus, we present a primary investigation of magneto structural properties of Co_2MnSiC based glass-coated microwires. The choice of glass-coating microwire physical form is due to the interesting magneto-structural behavior of Heusler-based glass-coated microwire [19–26].

Co_2MnSiC glass-coated microwires, studied in the current paper, are prepared by using Taylor-Ulitovsky method developed since 1960s [27]. The Taylor-Ulitovsky method involves the rapid quenching processes used to prepare Heusler alloys glass-coated microwires [19–23]. Initially, this technique was developed for the preparation of non-magnetic glass-coated microwires [27]. However, since 70-s almost the same preparation method has been employed for preparation of amorphous magnetic microwires [28–31]. Recently, the preparation of glass-coated microwires with metallic nucleus diameters, ranging from 0.5 to 100 μm, using this technology was reported by several authors [29–36]. The main benefit of this low-cost preparation method is that it allows the rapid (up to a few hundred meters per minute) production of thin and long (a few kilometers) microwires with a wide diameters range. This method is also suitable for the preparation of glass-coated microwires with greater mechanical properties [31,32]. The glass coating on the microwires can provide additional benefits, such as improved insulation, protection against environmental factors and improved mechanical properties of fragile crystalline alloys [31]. Furthermore, biological applications would benefit from the availability of a biocompatible thin, flexible, insulating, and highly transparent glass coating [33,34]. Accordingly, Co_2MnSiC-based Heusler microwires are a promising smart material for a wide range of technological applications. As far as we are aware, the production, structural, mechanical, and magnetic characterization of Co_2MnSiC-based Heusler glass-covered microwires have not been substantially examined. The structural and magnetic properties of Co_2MnSiC microwires will thus be the primary focus of the current work in order to demonstrate their potential applications in cutting-edge spintronics.

In the current study, we want to highlight for the first time the magneto structural properties of Co_2MnSiC, the effect of external magnetic field and the temperature on its magnetic behavior. Unique magnetization thermal stability has reported for wide range of temperature (5-300 K) and magnetic field. In addition, we detected a critical magnetic field where the magnetization curves shows a perfect thermal stability. The unique magnetic properties together with the other well-known physical properties of Co_2MnSiC-based glass-coated microwires make them a promising candidate for many interesting multifunctional applications.

2. Materials and Methods

For preparing Co_2MnSiC alloy we follow the same procedures reported in [21,35], but with adding Carbon with proper percentage. High purity cobalt (99.99 %) (50 at. %), manganese (99.9 %) (24.6 at. %), silicon (99.99 %) (25 at. %), and carbon (99.9 %) (0.4 at. %), are weighed and placed in a ceramic crucible. Then, we used the arc furnace to melt the mixture of alloy under vacuum to prevent the oxidation. The melting process is repeated 5 times to have a homogenous Co_2MnSiC alloy. Once the Co_2MnSiC alloy is ready, the ingot moved to the next step where we be able to fabricate Co_2MnSiC microwires covered by insulating (Duran) glass-coating using the Taylor-Ulitovsky method. The Taylor-Ulitovsky method has several advantages over other methods for preparing glass-coated microwires. One advantage is that it allows for the preparation of microwires with a very thin glass coating, typically a few micrometers in thickness. This thin coating allows for the preservation of the electrical and magnetic properties of the microwire metallic nucleus, making the resulting microwires useful for a variety of applications. The fabrication process is described in detail in several previous works [19–21,35,36]. The diameter of the metallic nuclei, d, was then determined by controlling the speed of wire drowning, molten alloy temperature and receiving bobbin rotation speed. To complete the quick melt quenching process, the produced microwire passes through coolant stream [21,35,36]. Through scanning electron microscopy (SEM), we deliberate that Co_2MnSiC glass-coated microwires have a metallic nucleus diameter, d, of 10.4 μm and total diameter D_{total} = 11.2 μm with aspect ratio, $\rho = d/D_{total} = 0.90$. This manufacturing method is particularly beneficial for alloys containing Mn due to fast alloy solidification, allowing it to protect against oxidation by the insulating glass coating [21,37]. Therefore, this procedure proves suitable for production of such materials, while achieving desired results in terms of quality control.

For investigating the magnetic properties of the Co_2MnSiC-based glass-coated microwires, we used a Physical Property Measurement System (PPMS) (Quantum Design Inc., San Diego, CA). We measured the magnetization curves for magnetic field, H, parallel to the wire axis, where the easy magnetization axis is expected due to the shape magnetic anisotropy. The measurements were performed at a wide range of temperature (5- 300 K) and magnetic fields strength (50 Oe -20 kOe). In addition, we studied the magnetic behavior under zero field cooling, heating, and cooling field to check the possible magnetic phase transition or irreversibility behavior. The morphological, chemical composition and the microstructure did by using energy dispersive X-ray spectroscopy (EDX), X-ray diffraction (XRD) BRUKER (D8 Advance, Bruker AXS GmbH, Karlsruhe, Germany). The Cu K_α (λ = 1.54 Å) radiation has been used in all the patterns. For microstructure investigation, we used high-resolution transmission electron microscopy (HR-TEM) (JEOL JEM2100).

3. Results

3.1. Structural Properties

Table 1 shows the results of an EDX/SEM examination done to determine the chemical composition of Co_2MnSiC glass-coated microwires and compared with Co_2MnSi sample. The composition of the metallic nucleus evaluated by EDX/SEM is somewhat different from the stoichiometric one

(Co_2MnSiC). This slight variation caused by the preparation procedure's characteristics, which comprised alloy melting and casting. We evaluated at the actual composition of ten different places to see how much the variation is. The atomic average composition of $\mathbf{Co_{50.4}Mn_{23.6}Si_{25.6}C_{0.4}}$ for Co_2MnSiC validated for all sites. An elevated Si content attributed to the interfacial layer between the glass coating and the metallic nucleus [37]. The Co, Mn, and Si at. % are almost similar for Co_2MnSiC and Co_2MnSi alloys (see Table 1).

Table 1. Atomic percentage of Co, Mn, Si and C elemental composition in Co_2MnSiC and Co_2MnSi glass-coated microwires.

EDX spectrum	Av. Co(at %)	Av. Mn(at %)	Av. Si (at %)	Av. C (at %)
Co_2MnSi-MWs	51±0.6	23.9±0.5	25.1±0.7	-
Co_2MnSiC-MWs	50.4±0.2	23.8±0.3	25.4±0.6	0.4±0.1

To confirm the chemical structure composition and their distribution at Co_2MnSiC glass-coated microwires we performed the elements mapping by using the high-resolution transmission electron microscopy (TEM) supported by EDX. Figure 1 illustrates the homogenous distribution of Co, Mn, Si and C elements at a single Co_2MnSiC glass-coated microwire. The image cross section does not show a perfect circular shape due to the distortion due to not exactly perpendicular cutting process, which results in an oval image shape. In addition, at the edge of the image, the color shows more contracted color due to the either distortion or the interfacial layer, but at the rest of microwire the perfect homogenous distribution is obtained. The fine details appeared in Figure 1d and 1e come from small pieces of glass coating, as evidenced by the increase in the Si percentage content.

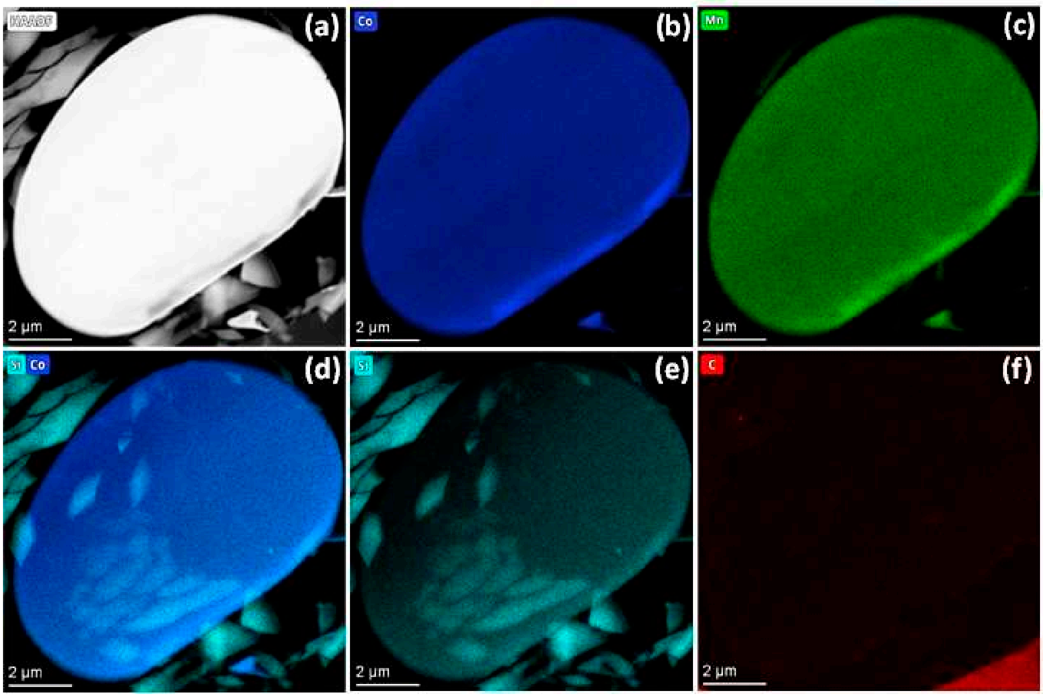

Figure 1. TEM image (**a**)-(**f**) with energy-dispersive X-ray (EDX) mapping for single Co_2MnSiC glass-coated microwires for (Co, Mn, Si and C).

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Figure 2 illustrates the X-ray diffraction (XRD) patterns of the Co_2MnSiC glass-coated microwires measured at room temperature (RT). All Miller indices are labelled on the patterns. As illustrated in Figure 1, there is a wide halo at 2θ ≈ 22º, commonly attributed to the presence of an amorphous glass-coating layer, also observed in our previous works [19–21]. The presence of (220), (400), and (422) peaks in the XRD pattern must be attributed to the cubic structure [38]. Accordingly, it is expected the presence of the austenite phase at room temperature in studied Co_2MnSiC samples.

As a result, the entire diffraction pattern has been successfully identified by the existence of the cubic austenite structure. We should state that the lack of (111) and (200) superlattice diffraction peaks confirms the presence of an A2-type cubic structure [39]. Indeed, no secondary phase was detected in all the XRD patterns. To evaluate the grain size, Dg, related to each peak, we used the Debye Scherrer formula [39,40]:

$$D_g = K\,\lambda/\beta\,\cos 2\theta \qquad (1)$$

where, K is a dimensionless form factor with a value of roughly 0.94 (which might vary depending on the actual shape of the crystallite), the experimental XRD wavelength (Cu-K (alpha) = 1.54), and β present the whole width at half maximum of the XRD peaks. Table 2 summarizes the differences of the microstructure between the Co_2MnSiC and Co_2MnSi glass-coated microwires, where a notable reduction in D_g and lattice parameters are observed.

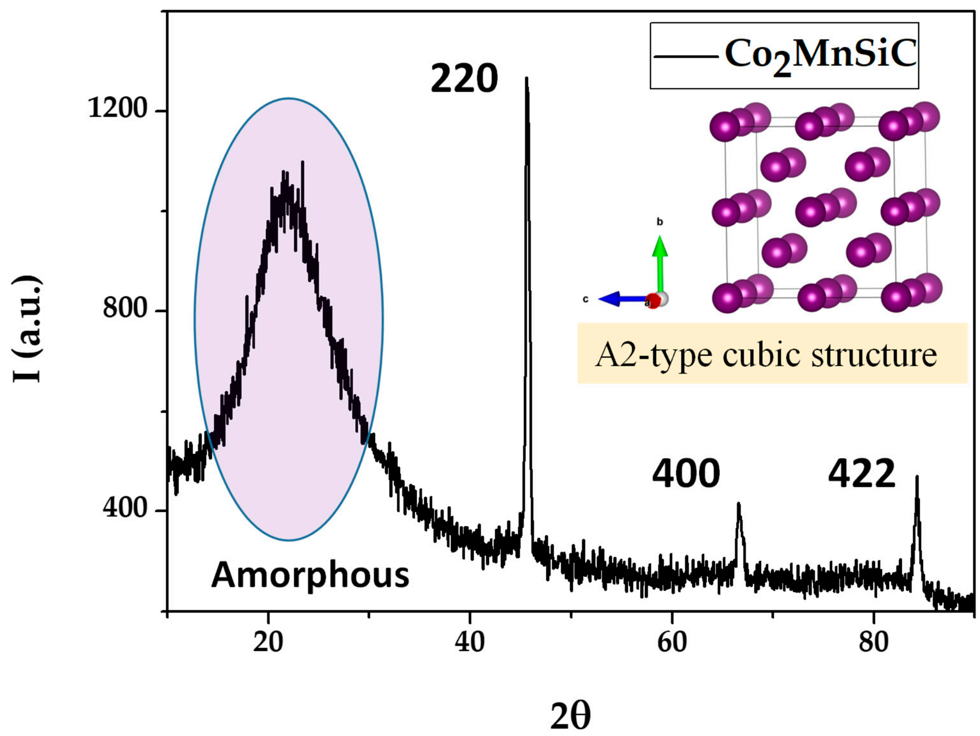

Figure 2. X-ray diffraction profile of Co_2MnSiC glass-coated microwires measured at room temperature.

Table 2. The average grain size, lattice parameter and the microstructure ordered of Co_2MnSi and Co_2MnSiC glass-coated microwires.

Parameters	Co_2MnSi-MWs	Co_2MnSiC-MWs
D_g (nm)	46±0.7	29.2±0.6
a (Å)	5.62	2.85
Ordered	$L2_1$ & B2	A2

The average Dg is about 29.2 nm, which is lower than that we reported for Co_2MnSi-based glass-coated microwires (Dg = 46 nm). The reduced Dg –value can be related to several factors, such as doping by small amount of Carbon or higher quenching rate due to thinner glass-coating thickness (0.4 µm for Co_2MnSiC microwire versus 5 µm for Co_2MnSi microwire). As discussed elsewhere, the average grain size substantially affects the magnetic properties of nanocrystalline materials [41]. Accordingly, such reduced Dg - value can substantially affect the magnetic properties of Co_2MnSiC glass-coated microwires as will be illustrated in the magnetic characterization part.

3.2. Microstructural Investigation

In this section, we only concentrate on the microstructure investigation of Co_2MnSiC to make sure of its initial properties and agree with XRD finding. Figure 3 shows the selected area electron diffraction image of single Co_2MnSiC glass coated microwires obtained by the HR-TEM. As illustrated in Figure 3a and 3b, there is an evident crystalline phase with an interplanar spacing of 0.24 nm. The Fast Fourier transforms, FFT, and SAED pattern confirm the cubic structure (see Figure 3c and 3d). The first three rings can be indexed with the (hkl) values (220), (400) and (422), which are consistent with the XRD results (see Figure 2). The clearly visible lattice bright points confirm the high crystallinity of the Co_2MnSiC. The interplanar spacing of 0.24 nm is equivalent to the (220) plane of the cubic Heusler phase of Co_2MnSi [42]. The main difference between the microstructure of Co_2MnSi and Co_2MnSiC is a fully disordered A2 cubic structure, as-compared to the $L2_1$ (ordered) and B2 (disordered) cubic structure observed in Co_2MnSi microwires [42,43]. Such difference can be related to either the Carbon doping or different fabrication conditions mainly associated with the thinner glass-coating for Co_2MnSiC microwire.

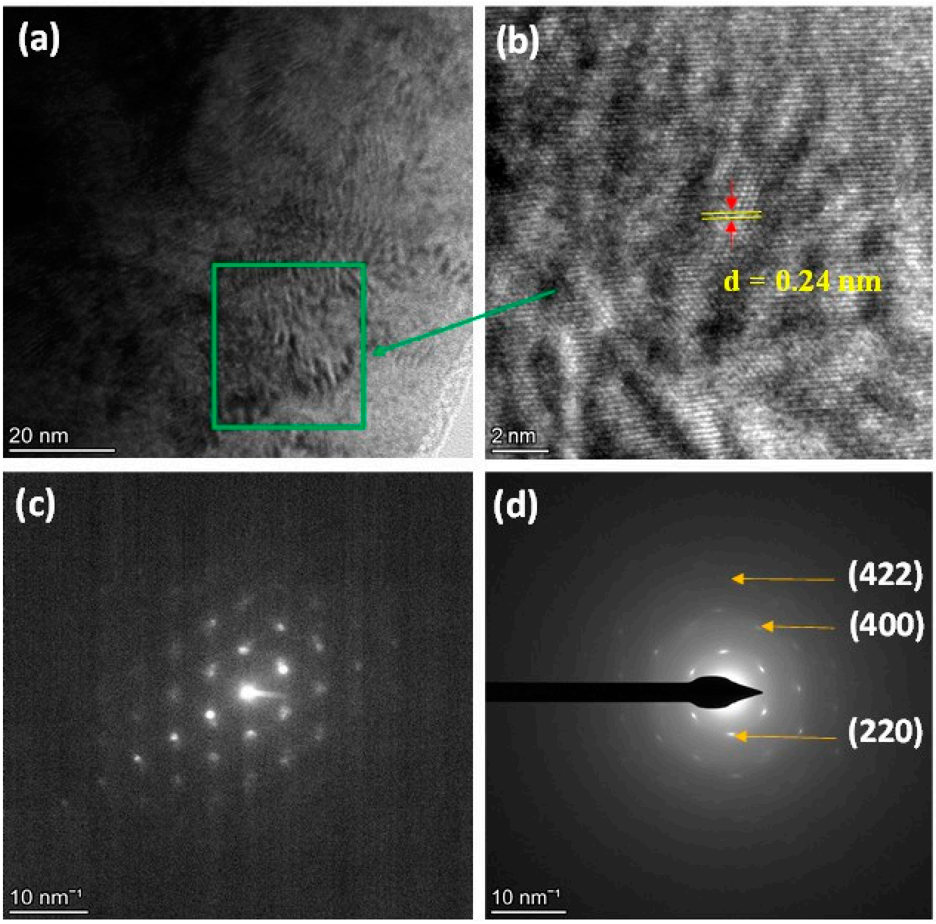

Figure 3. (**a**) and (**b**) HRTEM image of Co_2MnSiC glass-coated microwires for green rectangular region (**c**) and (**d**) FFT and SAED pattern acquired from rectangle region.

3.3. Magnetic Properties

This section deals with the magnetic behavior studied between 300 K and 5 K. As described in the experimental section, we employed the PPMS to explore the magnetic properties of Co_2MnSiC and Co_2MnSi glass-coated microwires over a wide temperature, T, and magnetic field, H, ranges. Figure 4 depicts the M/M_{5K} (H) curves, measured at various temperatures. The M/M_{5K} (H) loops exhibit ideal saturated curves between 300 and 50 K, however at T 50 K; a noticeable deviation from the saturation begins to occur. Such deviation increases with T decreasing (see the inset of Figure 4a). The peculiarity of the Co_2MnSiC microwires with respect to at Co_2MnSi is the presence of a fully disordered microstructure with A2-type as described in Figure 2 and Figure 3. This A2-type microstructure breaks the antiferromagnetic order of Mn-Mn and enhances the paramagnetic effect at temperature below 50 K. For sample without Carbon, strong antiferromagnetic coupling Mn-Mn has detected (see Figure 4b) for more details see ref. [21].

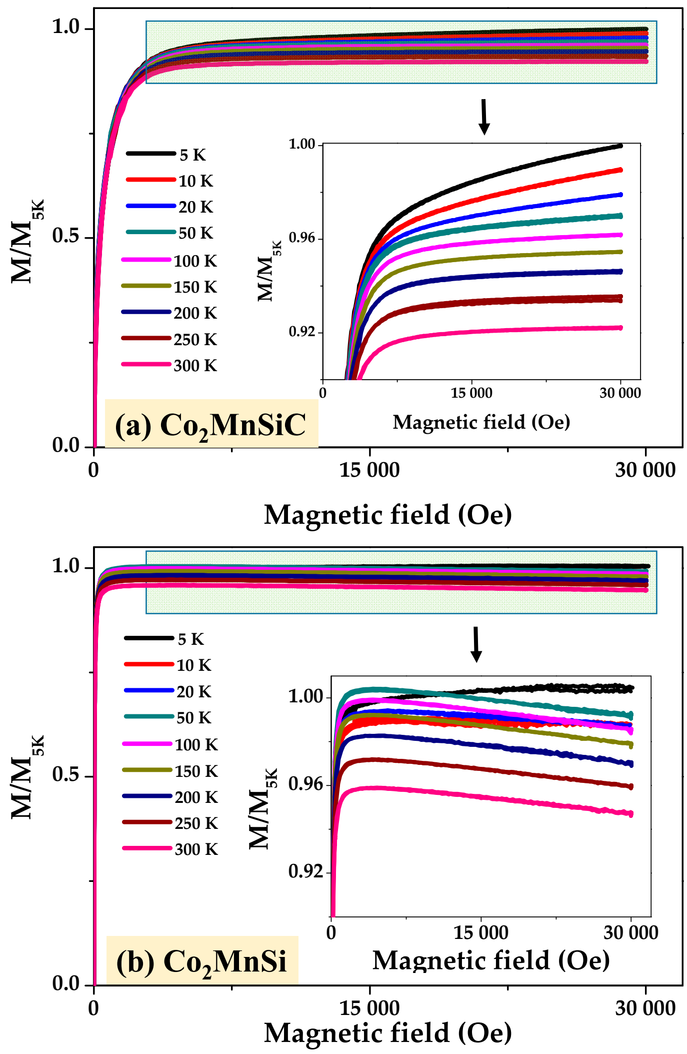

Figure 4. Magnetization (M/M_{5K}) vs. magnetic field curves of as-prepared Co_2MnSiC (**a**) and (**b**) Co_2MnSi glass-coated microwires measured at temperature range 5 to 300 K. In set illustrates the high magnification of magnetic curves with temperature, where the paramagnetic effect start appear at T = 50 K for Co_2MnSiC and antiferromagnetic effect for Co_2MnSi-glass coated microwires at T < 50 K.

The complete M/M_{5K} (H) curves for Co_2MnSi and Co_2MnSiC glass-coated microwires are shown in Figure 5. Such M/M_{5K} (H) loops, measured at magnetic field ±30 kOe almost perfectly match at temperatures 300-5K. Small differences were observed only at the saturation part of the M-H loops, as discussed in the previous paragraph. As illustrated in Figure 5a and 5b, the Co_2MnSiC sample show higher coercivity and lower normalized remanent compared to the Co_2MnSi sample at low and

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high temperature. These variations is due to the changing of the microstructure, which affect the magnetic microstructure of the sample and its response with variation of the temperature and the magnetic field.

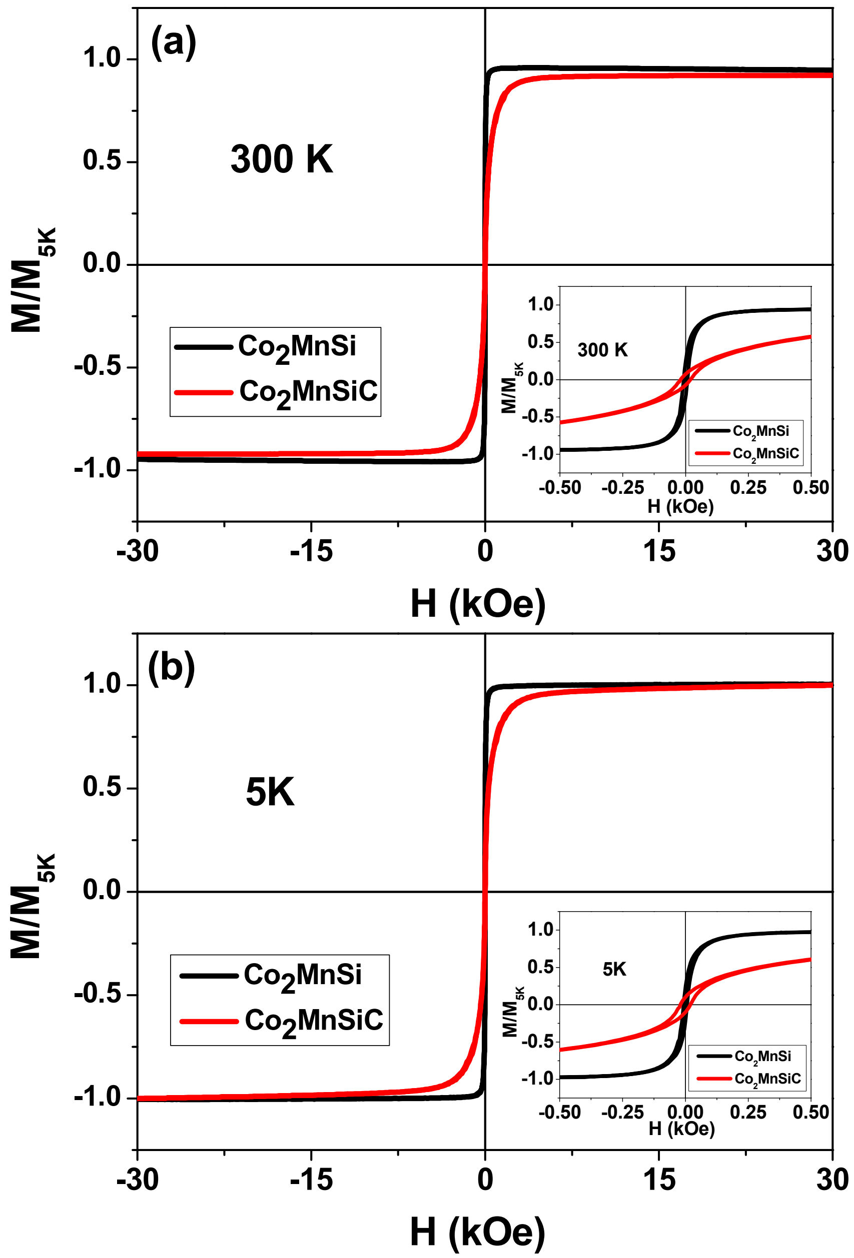

Figure 5. (**a**) and (**b**) M-H Hysteresis loops, measured in an applied magnetic field (±30 kOe) parallel to the axis of the microwires at different temperatures from 5 K to 300 K for as-prepared Co_2MnSi and Co_2MnSiC glass-coated microwires, respectively. The inset of figures are low magnification scale of magnetic field and M/M_{5K}.

The main magnetic parameters, such as coercivity, Hc, and magnetic remanence, M_r, extracted from low field M/M_{5K} (H) loops measured at different temperature are shown in Table 3. From M/M_{5K} (H) loops, we can deduce low Hc -values showing average Hc ≈ 19.4 Oe for Co_2MnSiC sample and the average of Hc ≈ 6.9 Oe for Co_2MnSi sample at all range of measuring temperature, illustrating soft magnetic properties of studied microwire. The temperature dependence of Hc and M_r show unique stability with temperature (see Table 3). The in-plane coercivity of Co_2MnSiC glass-coated microwires show rather stable Hc –value, where the differences between the lowest and the highest value of Hc, i.e., ΔHc is around 0.3 Oe (compared to 4 Oe for sample without Carbon). In addition, the differences

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between the normalized M_r (max) and normalized M_r (mini), ΔM_r is about 0.03 as shown in Table 3. Observed unusual high temperature stability of Hc and M_r makes this new alloy, i.e. Co_2MnSiC glass-coated microwires, as a promising for application in magnetic sensing. For Co_2MnSi-based glass coating microwires, i.e. without Carbon doping, the Hc and M_r temperature dependencies also show a quite stable behavior, but ΔHc is around 4 Oe and ΔM_r = 0.05. Therefore, studied Co_2MnSiC microwire present better thermal stability of Hc, that can be attuited by Carbon doping of the Co_2MnSi-glass coated microwires or higher quenching rate associated with thinner glass-coating. Accordingly, the energy loss of the ferromagnetic materials becomes stable for a temperature range 300 to 5 K, which is very important for magnetic storage media, sensors, and energy-efficient motors devices.

Table 3. The coercivity and normalized remanent variation with temperature for Co_2MnSi and Co_2MnSiC glass-coated microwires.

	Co_2MnSi-MWs		**Co_2MnSiC-MWs**	
T(K)	**Hc(Oe)**	**Mr**	**Hc(Oe)**	**Mr**
5	7±1	0.22±0.01	19.8±0.5	0.096±0.001
10	6 ±1	0.19±0.01	19.8±0.5	0.1±0.001
20	5±1	0.18±0.01	19.9±0.5	0.096±0.001
50	7±1	0.2±0.01	20±0.5	0.092±0.001
100	6±1	0.2±0.01	20±0.5	0.09±0.001
150	6±1	0.2±0.01	19.9±0.5	0.08±0.001
200	8±1	0.2±0.01	19.8±0.5	0.08±0.001
250	8±1	0.22±0.01	19.8±0.5	0.07±0.001
300	9±1	0.23±0.01	19.6±0.5	0.07±0.001
Δ	4 (Oe)	0.05	0.4 (Oe)	0.03

It is critical to analyze the completely magnetic behavior with temperature in order to examine its thermal stability, which is a critical physical quality in determining its potential for spintronics applications. Furthermore, the temperature dependence of magnetization can provide important information on magnetic phase transformation. The magnetization dependence versus temperature (M vs. T), i.e., zero field cooling, ZFC, and field cooling, FC, throughout a wide range of magnetic field (H = 50 Oe to 20 kOe) and temperature range (5 to 300 K) are shown in Figures 6 and 7. The as-prepared Co_2MnSiC and Co_2MnSi glass-coated microwires were cooled down from 300 K to 5 K under an applied low magnetic field (H = 50 Oe) in the Field cooling protocol, causing the random magnetic moment vectors to freeze parallel to the applied field at low temperatures. Figure 6 shows the ZFC, FC and FH measuring at low magnetic field. For Co_2MnSiC sample, all magnetization curves show perfect ferromagnetic behavior without any magnetic phase transition, where the M/M_{5K} ratio has a monotonic increase by decreasing the temperature from 300 K to 5 K. The differences between the $M/M_{5K\,(300\,k)}$ and $M/M_{5K\,(5K)}$, i.e., $(\Delta M/M_{5K})$ ZFC = 0.16, $(\Delta M/M_{5K})$ FC = 0.19 and $(\Delta M/M_{5K})$ FH = 0.18. Such a small differences in the $(\Delta M/M_{5K})$ between the ZFC, FC and FH magnetization curves must be related to the changing in the internal stresses originated by the glass-coating under changing the magnetic field and the temperature. Meanwhile, for Co_2MnSi glass-coated microwires large irreversibility with a blocking temperature T = 150 K has observed as show in Figure 6b. This irreversibility

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is stable at applying external magnetic field from 50 Oe to 20 kOe. This behavior illustrates the strong influence of Carbon to change the magnetic properties and it behaves at different magnetic fields and temperature.

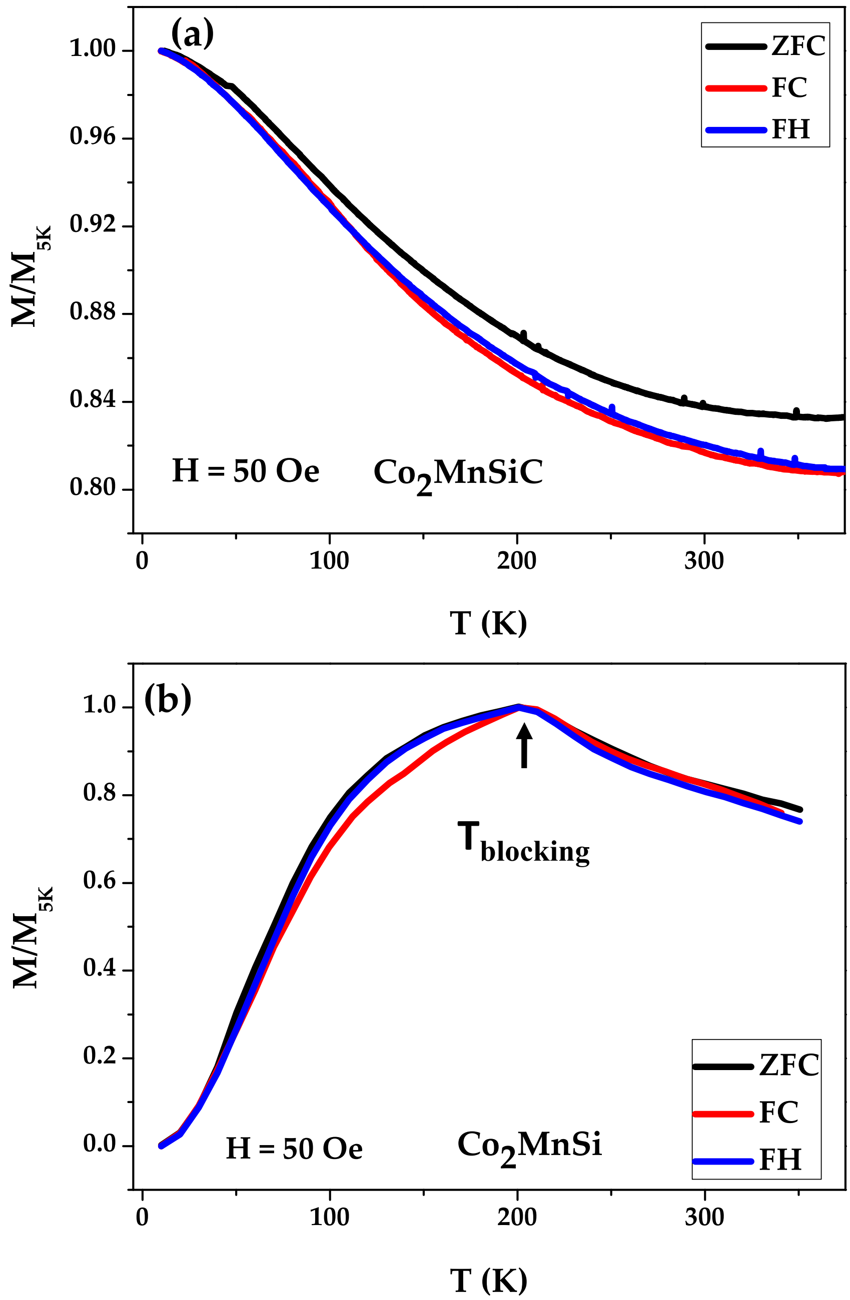

Figure 6. Zero field cooling (ZFC), field cooling (FC) and field heating (FH) of as-prepared Co_2MnSiC (a) and (b) Co_2MnSi glass-coated microwires.

Figure 7 depicts FC and FH applied at various magnetic fields ranging from 50 Oe to 20 kOe. All FC and FH magnetization curves exhibit ferromagnetic behavior over the entire temperature range. Magnetization curves, measured at low magnetic fields, such as 50 Oe and 200 Oe, present strong modification with temperature. The slope on M/M_{5K} (T) vanished when the applied external magnetic field was increased up to 1kOe, and the FC and FH curves became almost straight (see Figure 7a). Figure 7b shows how the FC and FH magnetization curves behave when an external magnetic field is applied. The M/M_{5K} (T) dependencies measured at different H illustrate the sensitivity of Co_2MnSiC glass-coated microwires on the temperature and the external magnetic field.

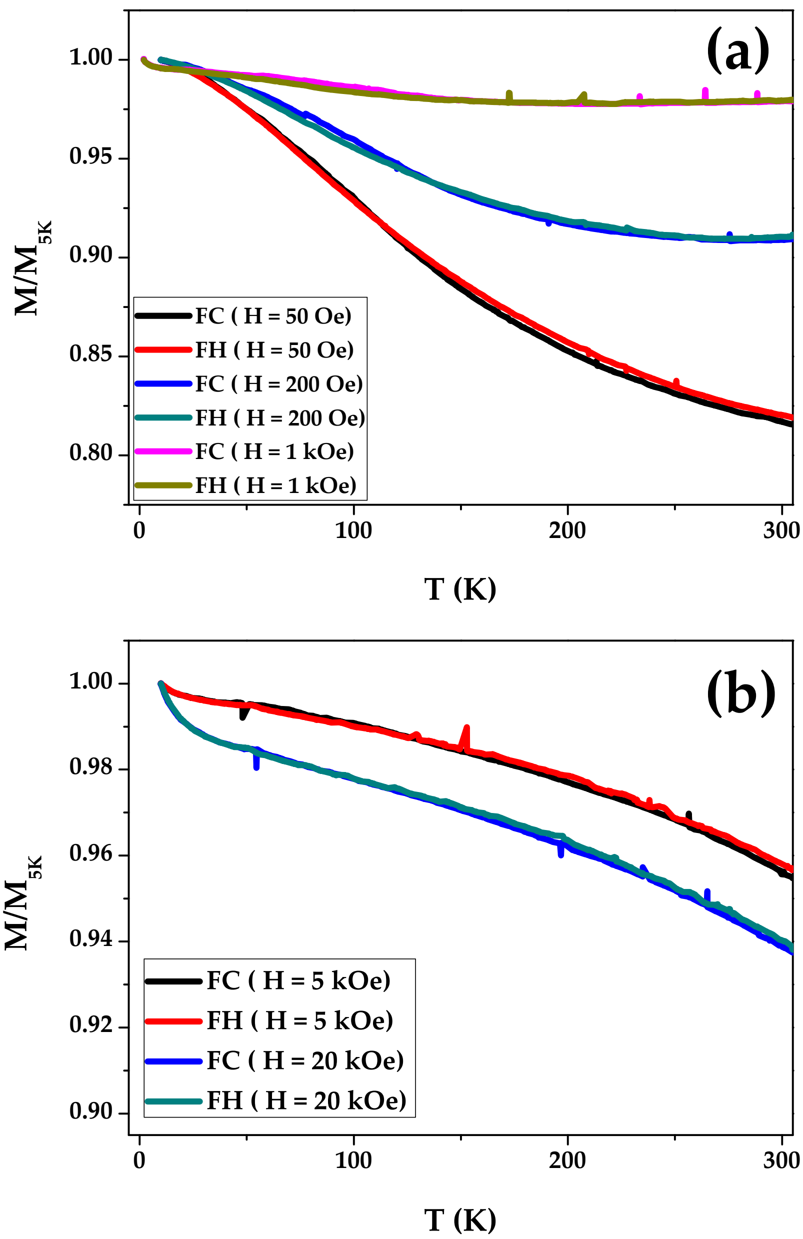

Figure 7. Temperature dependence of magnetization (M/M_{5K}) measured for as-prepared Co_2MnSiC glass-coated microwires with applied external magnetic field (**a**) H = 50 Oe, 200 Oe and 1 kOe, (**b**) H = 5 kOe, and 20 kOe.

From the FC and FH magnetization curves of Co_2MnSiC glass-coated microwires measured at different magnetic fields, we can estimate the magnetization thermal stability (ΔM) of each FC and FH magnetization curves of Co_2MnSiC glass-coated microwires. We proposed a phenomenal formula of (ΔM) which it depends on the difference between the maximum value of the magnetization and the minimum value of the magnetization at a specific range of temperature. As all FC and FH shows a ferromagnetic behavior and the maximum value of M/M5K measured at 5 K and the lowest value of M/M_{5K} measured at T = 300 K. Therefore, we can estimate the ΔM (%) for ΔT (the range of measuring temperature i.e. 300 – 5 K) by using this formula;

$$\Delta M\ (\%) = (M/M_{5K} - ((M/M_{5K})_{(T = 5K)} - ((M/M_{5K})_{(T = 300K)})) \times 100$$

$$\text{i.e., } \Delta M\ (\%) = (1 - \Delta M/M_{5K}) \times 100$$

All calculated values are summarized at Table 4.

Table 4. The estimation of thermal magnetization stability of FC and FH curves of as prepared Co_2MnSiC glass-coated microwire.

H (Oe)	ΔM (%) (FC)	ΔM (%) (FH)	ΔM (%) Av.
50	81	82	81.5
200	91	91.6	91.3
1000	97.3	98.1	97.7
5000	95.2	95.4	95.3
20000	93.6	93.8	93.7
Av.	91.6	92.2	91.9

As illustrated in Table 4, the minimum thermal magnetization stability detected for FC and FH magnetization curves at H = 50 Oe, at which it is over 80 %. The highest ΔM is observed at H = 1 kOe, at which ΔM is near 98 % i.e. the changing in the M/M_{5K} magnetization ratio with temperature is only 2 %, which mean very high magnetization thermal stability. In addition, the average magnetization thermal stability for all range of magnetic field is about 92 %. Such behavior was not observed in Co_2MnSi glass-coated microwires, as the FC and FH magnetization curves of Co_2MnSi microwires show a large irreversibility magnetic behavior at low temperatures. Thus, ΔM for Co_2MnSi glass-coated microwires has a low temperature stability as- compared to the Co_2MnSiC glass-coated microwires. Therefore, studied Co_2MnSiC glass-coated microwires is a suitable candidate for micro motors and generators devices based glass-coating microwires.

4. Conclusions

In summary, we studied the magneto-structural properties of novel Co_2Mn-Heusler alloys-based glass-coated microwires (Co_2MnSiC) prepared by using Taylor-Ulitovsky method. The structure analysis proof the formation of nanocrystalline structure with A2-type cubic structure due to the lack of (111) and (200) superlattice peaks. The magnetic measurements reveal the unique thermal stability over a wide range of temperature 300 -5K, where the H_c and M_r shows almost stable tendency with decreasing the temperature. ZFC, FC and FH magnetization curves show a regular ferromagnetic behavior by decreasing the temperature from 400 K to 5 K at applied external magnetic field (H = 50 Oe and 200 Oe). At magnetic field 1 kOe FC and FH magnetization shows the lowest change with temperature. The unique thermal stability of Co_2MnSiC based glass-coated microwires with aspect ratio near to unity makes it an excellent candidate for advanced sensing applications. Additional investigations of Co_2MnSiC microwires with different aspect ratios and annealing influence on the magneto-structural properties of novel Co_2MnSiC based glass-coated microwires can reveal the role of internal stresses on observed thermal stability of magnetic properties.

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