THERMOELECTRIC PROPERTIES OF NANOSTRUCTURED Fe-Al ALLOY

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ABSTRACT

Thermoelectric materials are very important engineering materials because they can convert waste heat into electricity. Thermoelectric generators are solid state devices with no moving parts and are silent, reliable and environmental friendly green method for power generation. While there exists several thermoelectric materials most of them are made of materials such as Bi-Te, Pb-Te based alloys which are expensive, at times toxic materials, and not mechanically strong. This makes them unsuitable for wide spread applications in power generation and refrigeration industries. In this investigation we developed a new thermoelectric material based on Fe-Al alloy system reinforced with multi walled carbon nanotube. The effect of carbon nano tube on the thermo electric properties of this material was also investigated.

Keywords: thermoelectric materials, figure of merit, powder metallurgy, automobiles, seebeck coefficient

INTRODUCTION

Thermoelectric materials have emerged as major engineering materials in recent years because of their applications as a source of alternate energy.[1-3]. One way to improve the sustainability of our electricity based energy source is through scavenging waste heat with thermoelectric generators. An enormous amount of heat is wasted in our society e.g., home heating, automobiles, power plants, oil and gas industry etc. Even if a small part (say 1%) of this waste heat is recovered it will immensely reduce the energy consumption and thus reduce global warming and pollution.

The efficiency of a thermoelectric converter is given by:

$$Z = \sigma S\ 2\ /\lambda = S2/\rho\ \lambda = PF/\ \lambda \qquad (1)$$

Where Z is called Figure of Merit, σ is the materials electrical conductivity, ρ is the resistivity, S is the Seebeck coefficient and λ is the thermal conductivity.

However, most often, a dimensionless term ZT is used to indicate the Figure of Merit:

$$ZT = \sigma S\ 2\ T/\lambda \qquad (2)$$

Here T is the operating temperature or the average temperature (T1+T2)/2 of the converter with T1 and T2 being respectively the cold and hot end temperature. The thermal conductivity λ is related to the transfer of heat through a material either by electrons (λ_E) or by the quantized vibration of lattice (λ_L) called phonons. Therefore $\lambda = \lambda_E + \lambda_L$. Then λ_L term depends on the crystal structure, rigidity, atomic masses of the material. It is also obvious from equation (2) that for high figure of merit, the material must have very high ratio of σ/λ i.e., the ratio of electrical conductivity and thermal conductivity must be as high as possible.

From equation 1 and 2, it also becomes evident that for high performance a thermoelectric material needs a high electrical conductivity (σ), a high Seebeck coefficient (S) and a low thermal conductivity (λ). These two terms are often combined into the quantity – Power factor (PF) = $S^2\ \sigma$, ideally, materials should have power factor as high as possible. Metals have high electrical and thermal conductivity but their seebeck coefficient is low. On the other hand, insulators have high seebeck coefficient but very low thermal and electrical conductivity. Semi- conductors have high seebeck coefficient and relatively high electrical and thermal conductivity which makes them ideal material for thermo-electrical applications.

Bismuth Telluride/ Lead Telluride based alloy systems are the most well-known materials used for thermoelectric devices. They have a figure of merit of order of 1 and none of the other materials are suitable or wide spread commercial applications. Although Bi-Te devices have good energy conservation efficiency, the high cost of their raw materials, toxicity and low mechanical strengths makes them unsuitable for wide spread applications and use. Many thermoelectric materials are expected to operate at elevated temperatures for a long period of time without deterioration of their properties and performance. Therefore, for practical and commercial applications we need to develop new thermoelectric materials which (a) do not contain any toxic elements. (b) are mechanically strong and has high creep and fatigue strength (c) have great corrosion and high temperature oxidation resistance. (d) have good power factors and are made of materials which are abundantly available and inexpensive.

In this investigation we have developed a new thermo electric material based on Fe-Al alloy system reinforced with multi walled carbon nanotube. This material was processed by powder metallurgy technique and thermoelectric properties were characterized.

OBJECTIVE

Both Iron and Aluminum are abundantly available and inexpensive materials. Moreover, Phase diagram of Fe-Al alloy show that Fe-Al alloy with 16% Al could be a semi-conductor material. Therefore, our goal was to synthesize a thermo-electrical material out of this alloy system consisting of Iron and Aluminum. In addition, it was theorized that addition of Multi walled carbon nano tube in this alloy system will result in lower thermal conductivity but with higher electrical conductivity which will result in higher figure of merit. Fe-Al-MWCNT alloys will be mechanically strong having high yield strength and tensile strength, good fatigue strength and fracture toughness. In addition, they will also have high creep strength. These new thermoelectric materials with good figure of merit and better mechanical properties and durability could be commercially viable and significantly reduce the cost of thermoelectric materials. These new thermoelectric devices will have many advantages compared to existing Bi-Te, Pb-Te alloy systems such as long life, no moving parts, no emission of toxic gases, low maintenance and high reliability. Thus these devices can significantly reduce energy dependence of this nation and reduce pollution and greenhouse gas emission.

EXPERIMENTAL PROCEDURE

Fe-16wt%Al alloy was prepared from high purity, elemental iron and aluminium powders. The iron powder particles ranged between 45–250m and the aluminium powder particles ranged between 30-45m. Three different samples are prepared with 0%,1% and 2% of MWCNT addition to the Fe-16wt%Al. The metal powders were mixed in requisite proportions with 0.5 w/o N,N -Ethylenebisstearamide lubricant by conventional horizontal roll milling in a glass jar (ID 8 cm, length 20 cm) with 2000 g chrome steel balls (7/16 dia) for one hour. Two fifty grams of the metal powder and lubricant mixture were transferred to a steel cylindrical die (SPEX, ID 32 mm) and compacted at 0.5MPa (36tsi) by single action pressing in a Dake hydraulic press. The green compacts were then sintered in a VFS sintering furnace in a 400m partial pressure argon gas atmosphere. The furnace was programmed to heat at 16°C (30°F) per minute to 313°C (595°F) and soak for 60 min to burn off the lubricant. Next, the temperature was increased, at 16 °C/min, to 593°C (1100°F), just below the melting temperature of aluminium, and held for 6 hrs. to promote solid state sintering. The temperature was then increased, at 16°C/min, to 1260°C (2300°F) and held for 6 hours to promote densification followed by a gas quench. These samples are then examined for their Thermal conductivity, Electrical conductivity and Seebeck coefficient. These values are used to calculate the Figure of merit (ZT) which gives determines the efficiency of thermoelectric materials.

RESULTS AND DISCUSSIONS

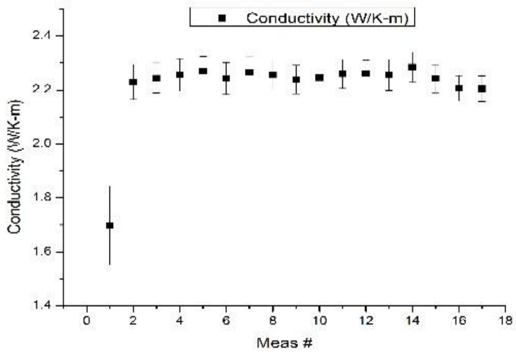
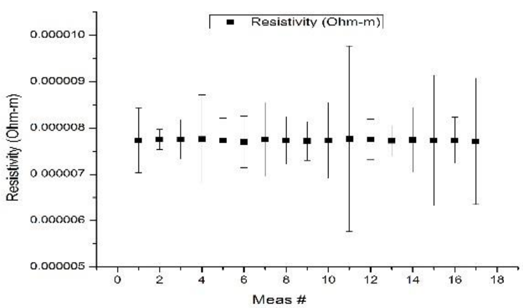


Figure 1



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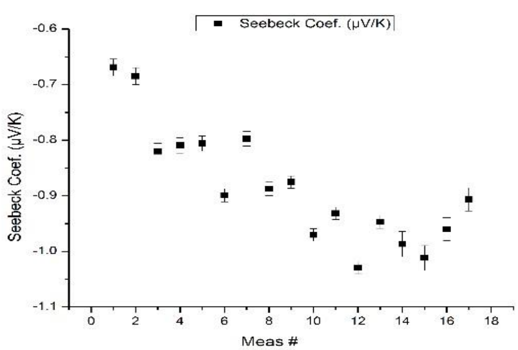

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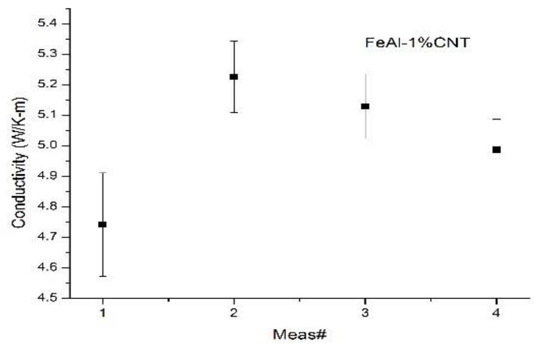

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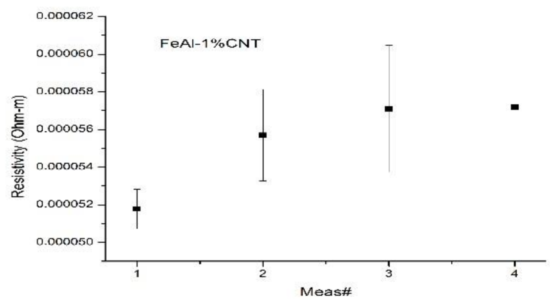

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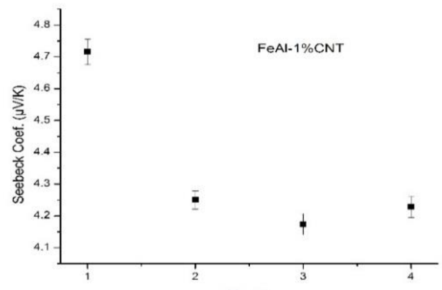

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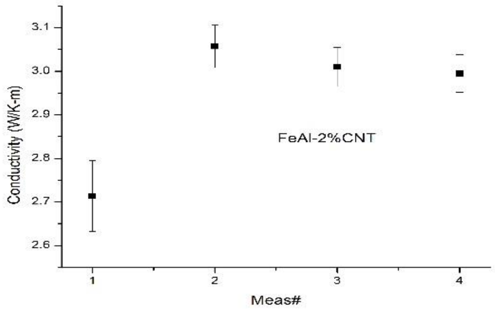

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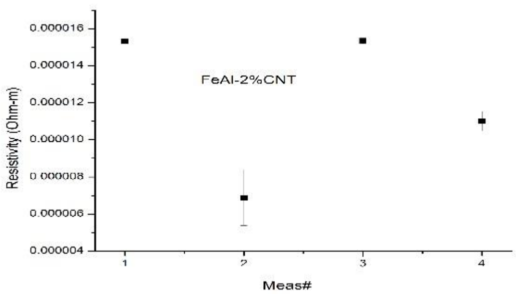

Figure 8

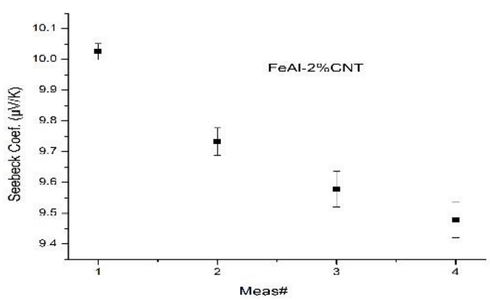

Figure 9

Figures 1,2 and 3 show the thermal conductivity, Electrical resistivity and Seebeck coefficient of Fe-16%Alloy without presence of any MWNCT. While figures 4,5 and 6 show the effect of addition of 1% MWCNT in Fe-16%Al Alloy. The addition of 1% MWNCT has resulted in lower electrical resistivity which means higher electrical conductivity and higher Seebeck coefficient. Figures 7,8 and 9 show that the addition of 2% MWCNT in Fe-16%Al alloy. This shows that 2% addition of MWCNT will result in increase in Electrical conductivity and Seebeck coefficient which resulted in high figure of merit. Table 1, summarizes this results. 2% MWCNT alloy has very high figure of merit. It appears that addition of MWCNT causes electron scattering and there by reduces Thermal conductivity. Table 1 shows the measurements of the Thermal conductivity, electrical resistivity, Seebeck coefficient and figure of merit for the samples with 0%,1% and 2% MWNCT.

Table 1

	Thermal Conduct (W/k.m)	Electrical resistivity (Ohm-m)	Seebeck Coefficient (S)	Figure of merit (ZT)
0%	2.2	$8*10^{-6}$	-0.9	0.00116
1%	5.2	$5.6*10^{-5}$	4.2	0.0213
2%	3	$1*10^{-5}$	9.5	0.1

CONCLUSIONS

In this investigation, we have developed a new thermo electrical material based on Fe-Al system reinforced with MWCNT. This material was processed by powder metallurgy technique. Sample with Fe-16wt%Al and 2% MWCNT had a figure of merit of 0.1. Even though this figure of merit is less than Bi-Te and Pb-Te system, there is a potential for improving the figure of merit with this alloy by making it nanostructured and by addition of Silicon in this alloy system. Currently investigation is under way to further improve the figure of merit of this alloy.

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