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Annealing Effect on Magneto-impedance in CoSiB Wires

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Abstract

In this study, thermal treatments dependence of Magneto-impedance (MI) effect in $Co_{72.5}Si_{12.5}B_{15}$ wires has been investigated. Wires were annealed at 460 °C for different times (1-400 min). It was found that low time annealed leads to increase in magnetic softness. The largest change in the MI was observed at 1 MHz frequency value. It was determined that maximum MI, coercivity (H_c) and maximum field sensitivity (S) values were 247%, 1.28 A/m and 1.35% per A/m respectively in the wire annealed at 460 °C for 10 minutes. This high MI and field sensitivity value occurring in low annealed time shows that this wire can be used in the design of low magnetic field sensors.

Keywords: Amorphous wire; Magneto-impedance; Coercivity.

CoSiB Tellerin Manyeto-empedansında Isıl İşlem Etkisi

Öz

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Bu çalışmada $Co_{72.5}Si_{12.5}B_{15}$ tellerde Manyeto-empedans (ME) etkinin ısıl işleme bağlılığı incelenmiştir. Numuneler 460°C'de farklı sürelerde ısıtılmıştır (1-400 dakika). Düşük süreli ısıl işlemlerin manyetik yumuşaklıkta artışa yol açtığı bulunmuştur. MI değerinde en büyük değişim 1MHz frekans değerinde gözlenmiştir. MI, H_c ve maksimum alan hassasiyet (S) değerleri 460 °C'de 10 dakika ısıl işlemde sırasıyla %247, 1.28 A/m ve A/m başına %1.35 olarak belirlenmiştir. Düşük ısıl işlem süresinde ortaya çıkan bu yüksek MI ve alan hassasiyet değeri bu telin düşük manyetik alan sensörlerinin tasarımında kullanılabileceğini göstermektedir.

Anahtar Kelimeler: Amorf tel; Manyetoempedans; Koersivite.

1. Introduction

The magneto impedance (MI) effect in amorphous wire, strip and films has been interesting due to the possible technological applications of these materials. [1-12]. When a magnetic material carrying a low intensity, high frequency alternating current is subjected to an external magnetic field, it exhibits a sharp change in its electrical impedance. This effect is known as the magneto impedance (MI) effect [1, 2]. In sensitive magnetic field sensor designs, besides high MI variation, field sensitivity values have an important place. The field sensitivity value of the MI against the applied external magnetic field is calculated using equation 1 as follows [2].

$$S = d\left(\frac{\Delta Z}{Z}\right)/dH \tag{1}$$

Alloy composition is important in obtaining MI curves. Different domain structures are observed depending on the alloy composition [2]. The domain structure of a material obtained by rapid cooling is determined by the interaction between internal stresses and magnetostriction [2]. Accordingly, the sign and magnitude of the magnetostriction value has an important role in MI effect. Magnetostriction value in amorphous ferromagnetic wires is negative in Fe based wires, positive in Co-based wires and approximately zero in CoFe based wires [2, 13-15]. Depending on the sign and magnitude of the magnetostricrion value, MI curves show single or double peak behaviors.

Different annealing treatment, such as furnace and current has an important role in the exchange of MI data [16-20]. In $Co_{75}Fe_{4.2}Si_8B_{12}Nb_{0.8}$ wires, the change of MI effect with annealing was studied [21]. In this study, while the maximum MI value was observed at a temperature of 450 °C for 25 minutes, it was observed that the value of MI decreased due to the formation of nanocrystalline phases at annealed above 25 minutes. Annealing applied to amorphous materials causes changes in MI effect. Therefore, in this work the thermal treatments dependence of MI effect in $Co_{72.5}Si_{12.5}B_{15}$ wires was investigated.

2. Materials and Methods

The $Co_{72.5}Si_{12.5}B_{15}$ wires produced by the melt spinning technique were cut 10 cm long. Samples were annealed in air in a non-inductive tube furnace at temperature of 460 °C for different times (1-400 min). The M–H curves were obtained using a dc digital system; the coercivity (H_c) was derived from the M–H curves. Sample impedance was measured using HP4294 impedance analyzer and HP4294A probe. MI data were obtained at 100 kHz, 1 MHz, 5 MHz and 10 MHz frequencies with 5 mA constant amplitude ac current. In magneto impedance measurements, solenoid was used for the outer dc magnetic field. The application of the Dc current along the solenoid was controlled by a computer. MI measurement system is given in Fig. 1. The data from the impedance analyzer were collected and averaged by the computer at each step of the magnetic field. The average of the impedance data leads to a large reduction in noise / signal ratio and thus clearer MI effect curves. The MI ratio was calculated from the equation $\Delta Z/Z\ (\%)=100[Z(H) - Z(H_{max})]/Z(H_{max})$, where Z_{max} is the impedance measured at a magnetic field of $H \approx 7400$ A/m.

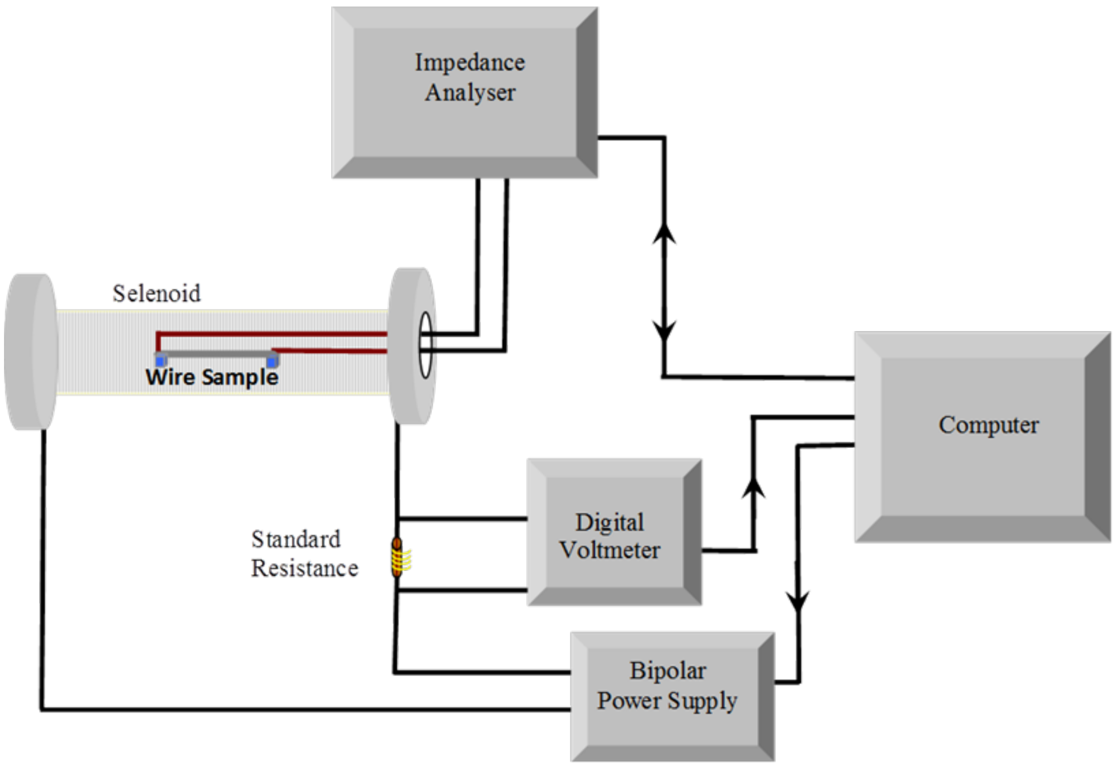

Figure 1: MI measurement system

3. Results

Fig. 2 shows MI curves for the as-received $Co_{72.5}Si_{12.5}B_{15}$ wire at various frequencies. MI values for 100 kHz, 1 MHz, 5 MHz and 10 MHz frequency values were measured as 67%, 149%, 81% and 68%, respectively. Fig. 3 presents the dependence of impedance on magnetic field in as-received and annealed samples in a particular case of 1MHz. Since the as-received CoSiB wire has a negative magnetostriction value, double peak behaviors were observed in the curves. [2, 14].

MI curves of $Co_{72.5}Si_{12.5}B_{15}$ wires, which are as-received and annealed at different times, was shown in Fig. 4. These curves were obtained by applying the frequency of 1 MHz. The highest value in magneto-impedance measurements was obtained on the wire which was annealed at 460 °C for 10 minutes. MI value for this wire was found to be 247%. It was determined that MI values changed with increasing annealed time and after 400 minutes the value decreased to 113%.

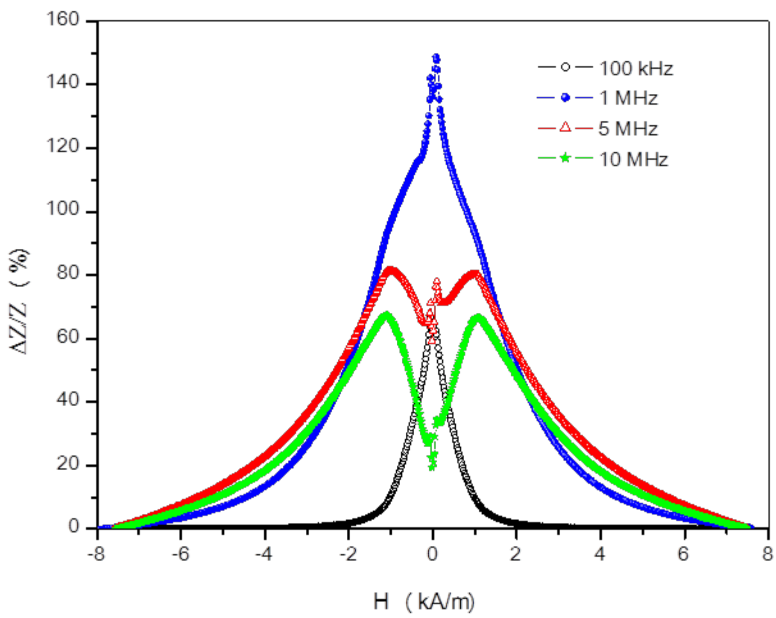

Figure 2: MI curves of as-received $Co_{72.5}Si_{12.5}B_{15}$ wire for different frequency

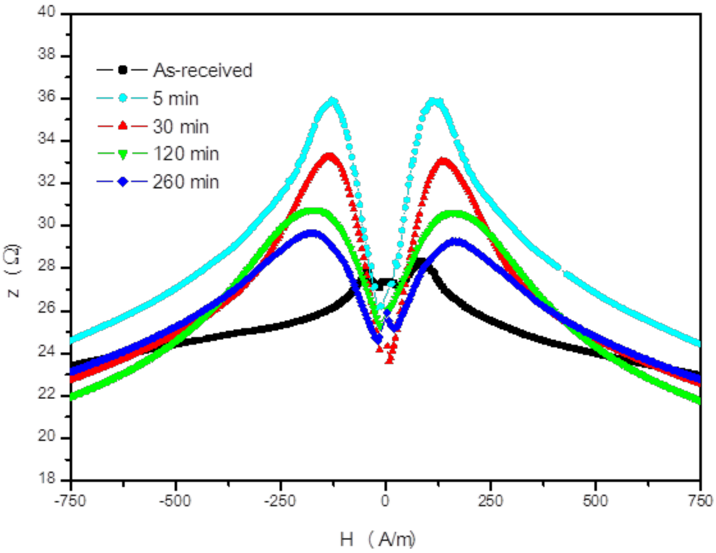

Figure 3: Impedance curves for as-received and annealed samples at 1 MHz

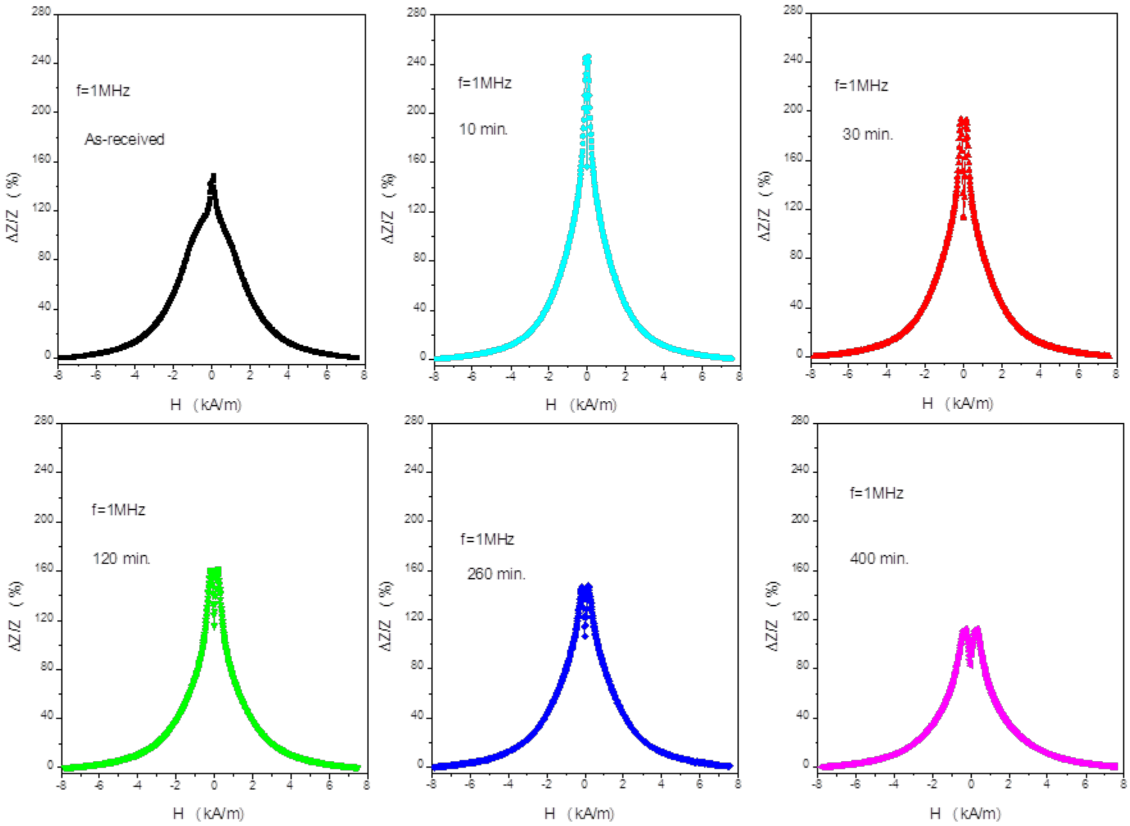

Figure 4: MI curves for as-received and annealed samples at 1 MHz

Fig. 5 shows variation of MI values as a function of annealing time for $Co_{72.5}Si_{12.5}B_{15}$ wires. The curves in Fig. 5 were obtained at the frequency values of 100 kHz, 1 MHz, 5 MHz and 10 MHz.

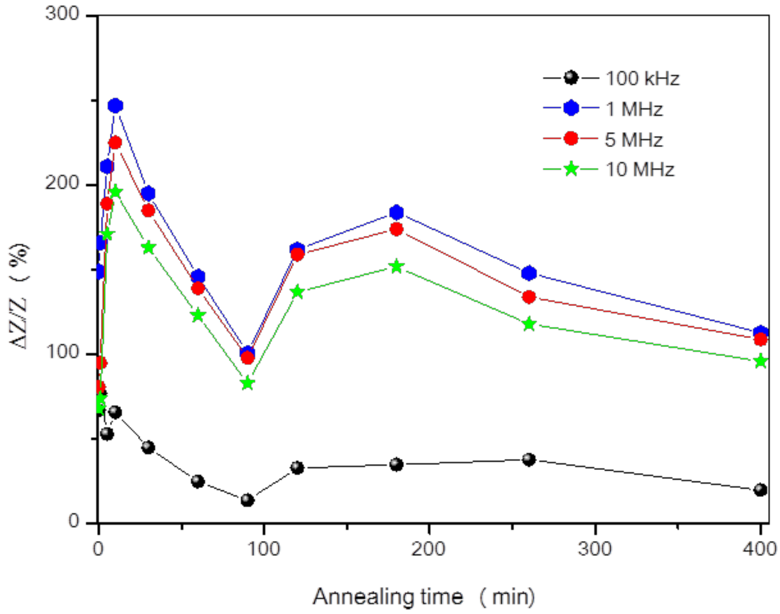

Figure 5: Variation of MI values as a function of annealing time

In the magnetic impedance measurements obtained for all frequency values, the greatest value has been observed on the wire annealed for 10 minutes. MI values were measured as 66%, 247%, 225% and 196% for the frequency values of 100 kHz, 1 MHz, 5 MHz, and 10 MHz respectively. As can be seen from Fig. 5, it is seen that MI values decrease sharply for all frequency values between 10-90 minutes. It was determined that MI values increased up to 180 minutes and decreased during the heat treatments over this time. MI values of $Co_{72.5}Si_{12.5}B_{15}$ wire annealed for 400 minutes. MI values were calculated as 20%, 113%, 109%, and 96% for 100 kHz, 1 MHz, 5 MHz, and 10 MHz frequency values respectively at 400 minutes annealing time.

Fig. 6 shows the magnitude of the MI and H_c values, a function of annealing time for the wires annealed at 460 °C. H_c and magneto-impedance changes were found to be compatible depending on the annealing time.

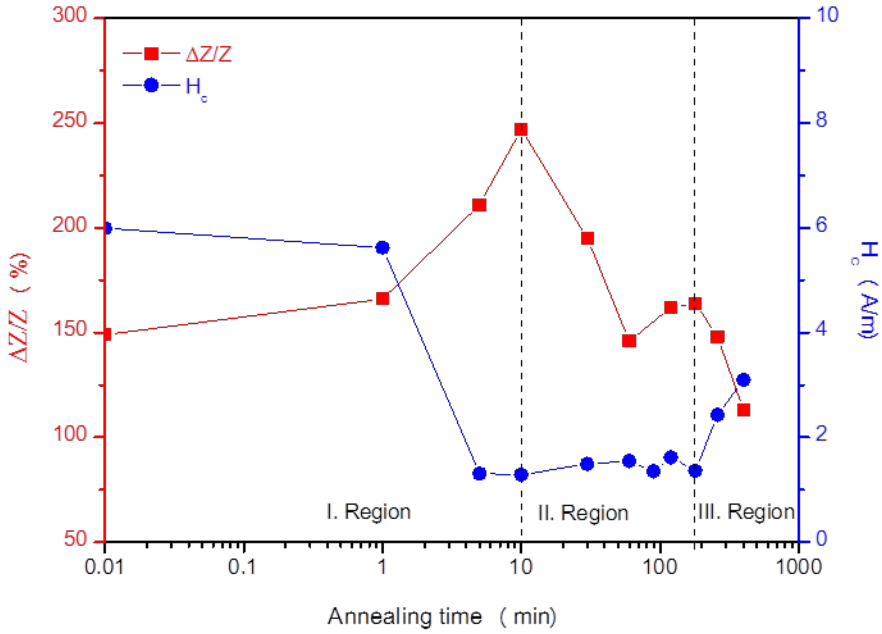

Figure 6: Variation of MI and H_c values with annealing time

Impedance and field sensitivity values (S) at ± 1000 A/m external magnetic field value were plotted in Fig. 7. In Fig. 7 (a), the double peak behavior against the applied external magnetic field is clearly seen. S values were determined as 1.2% per A/m and 1.35% per A/m in the positive and negative magnetic field directions, respectively (Fig. 7 (b)).

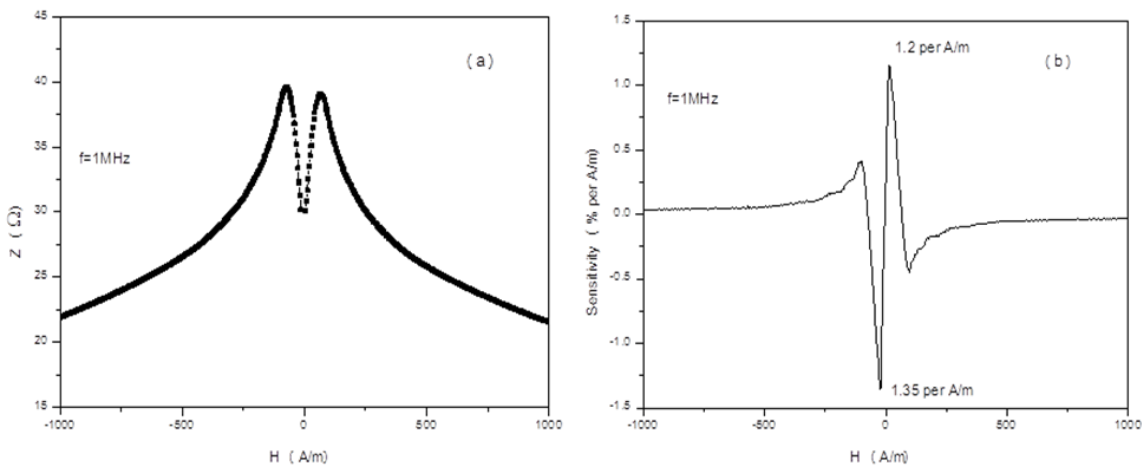

Figure 7: (a) Impedance, (b) field sensitivity values against the applied low field of the wire annealed at 460 C for 10 minutes. (f = 1 MHz)

4. Discussion

The magnetic permeability of the samples has an important role in the interpretation of MI data. The permeability of materials can be related to the skin effect. For a conductor carrying a sinusoidal alternating current, the penetration or skin depth, d, is given by the well-known expression [22, 23]

$$\delta = \left(\frac{2}{\omega\sigma\mu}\right)^{1/2} \text{and } Z \propto {}^{1}\!/_{\delta} \tag{2}$$

where σ is the conductivity, ω is the ac current frequency and μ is the permeability.

It is also well-known that the permeability of a magnetic material is proportional to the total anisotropy (K) of a sample. For amorphous and nanocrystalline materials the main contributions to the anisotropy are the magneto-elastic anisotropy (K_{me}), shape anisotropy (K_D) and the magneto-crystalline anisotropy (K_{mcrys}) [4]. The K_D contribution is similar in all samples since the lengths of the as-received and annealed samples are the same. For this reason, K_{me} and K_{mcrys} are considered in the interpretation of the data. The total anisotropy value of the sample is inversely proportional to the impedance value due to magnetic permeability. Bearing this in mind, the effect of the annealing time on (ΔZ/Z) (%) and H_c values can be divided into three regions (see Fig. 6).

As can be seen in Fig. 6, I. Region is low annealed time (up to 10 minutes), II. Region medium annealed time (30-180 minutes) and III. Region shows the annealed time over 180 minutes. In the low annealed time, it was determined that both the H_c value reached a minimum (1.28 A / m) and the magneto impedance value reached a maximum value (247%). Annealing up to 10 min relieves the internal stresses, thus reducing K_{me}, and hence increasing MI values.

In the II. Region, a very small increase in H_c values and a sharp decrease in magneto-impedance value were observed up to 120 minutes of heat treatment. Between 120-180 minutes, a partial increase in magneto impedance value and very small changes in H_c values were determined. This is related to the surface crystallization that occurs in the sample [4, 16]. In longer annealed time, in the III. Region (over 180 minutes), boron phases are formed in the building [21]. Due to the formation of these phases, magneto crystal anisotropy occurs in the amorphous structure and this leads to an increase in the total anisotropy in the sample. Therefore, it was determined that H_c values increased and MI values decreased due to the increase of total anisotropy.

Field sensitivity values are also important in magnetic field sensor designs of samples with high MI variation. In the literature, the field sensitivity value for the as-received $Co_{72.5}Si_{12.5}B_{15}$ wire was calculated as 0.22% per A/m [14]. In our study, S value was determined as approximately 1.35% per A/m in the negative magnetic field region as a result of the low-time annealed (Fig. 7 (b)). This shows that the soft properties resulting from the low-time annealed increase the S value.

5. Conclusion

In this study, we observed that annealing time had a great effect on MI curves of $Co_{72.5}Si_{12.5}B_{15}$ wire. Especially low annealed time has been found to lead to an improvement in the magnetic softness, leading to an increase in MI effect. It was determined that MI and H_c values were 247% and 1.28 A/m in the wire annealed at 460 °C for 10 minutes. In addition, the S value of the wire annealed during this low-time was calculated as 1.35% in the negative magnetic field direction and 1.2% in the positive magnetic field direction per A/m. Maximum MI and S values indicate that this wire is suitable for magnetic field sensor design. When annealed time was over 180 min, nanocrystalline phase growing up improves the magneto crystalline anisotropy and reduces the MI effect.

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