Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 23(2013) 2633−2637
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Adding effects of Ni and Mn on electromagnetic interference (EMI) shield of Sn-based architectural materials

Fei-shuo HUNG

Department of Travel Industry Management, Far East University, Tainan, Taiwan, China

Received 14 December 2012; accepted 20 March 2013

Abstract: It has been proved by the World Health Organization (WHO) that electromagnetic waves would bring threats to public health in the tourism environment. However, most of the recent research about the relationship between building materials and electromagnetic waves was mainly focused on the electromagnetic products. It has also been claimed that the related research can rarely been found. Generally, ecotourism more tends to emphasize on a development of a new product and uni-environment study. However, these studies did not concern much on the application for conformity of healthcare−living materials, particularly to those block high-transparency materials. Hence, this research approaches to conform the application of architectural technique for producing tin-based powder with the add-on of Ni and Mg, in order to discuss the fully anti-electromagnetic wave property of healthcare material. With a low-cost advantage, the application field of architecture defines the ternary powder system, namely Sn−Al−Ni (SAN) and Sn−Al−Mn (SAM). Additionally, the surface coating method can be implemented to review the influence of particle size, content ratio of Ni and Mn, stack effect, porosity and thickness to electromagnetic interference (EMI) mechanism.
Key words: Ni; Mn; electromagnetic interference (EMI) shield

1 Introduction

The previous study shows that most of the architectonical researches were more focused on the development of single technology product [1].

However, the practical use of building materials and applied design were ignored while this has led to a predicament of high technology and healthy building technique. Healthy building and nano technology are the most popular issue in this century, and green-healthy materials are keeping in demand due to the rare resources on the earth and the public appeal for green earth. At the same time, the nanotechnology industry has provided a lot of developing opportunity. For instance, the issue of new-developed structure, property and function of nano-materials can be built on other materials [2−4].

The ideal materials for EMI would be those that can absorb electromagnetic waves with good properties such as light, thin, functional and can be applied in a complex structure. Furthermore, EMI materials are expected to be functionally flexible, in terms of heat, pressure, corrosion, antifouling etc, and can be applied in a wide frequency range. Unfortunately, there is no such absorption material to fulfill the properties that have been mentioned previously. This resulted in a variety of anti-electromagnetic wave materials which have their own application field, and sometimes needed to combine to get a higher efficiency [5−7]. Hence, our investigation would be based on the tin alloy system that possesses good properties in cost, thermostability, corrosion, malleability, electric and heat conductivity [8,9].

EMI is always an issue for perpetual building [10−12]. There are still many researchers concentrating their EMI shield experiments on anti-UV or conductive powder [13], such as carbon or iron powder [14]. However, the applicability has been limited since the ingredients are dark in color and non-metal [15−17]. Therefore, we only consider Sn, Al, Mn and Ni that are good at EMI shielding effect and price competitiveness. On the other hand, a simple procedure has been implemented to produce the low-cost silver-white powder, namely Sn−Al−Ni (SAN), Sn−Al−Mn (SAM), and were coated to investigate the effect of EMI caused by particle size, content of Ni and Mn, and coating thickness [18,19].

Corresponding author: Fei-shou HUNG; E-mail: Fshung@cc.feu.edu.tw
DOI: 10.1016/S1003-6326(13)62778-8

2 Experimental

The powder and coating experiments were implemented at first to improve the nano-structure of powder. The first step was to investigate the correlation effect between EMI and the building-used ternary powder system, namely Sn−Al−Ni (SAN) and Sn−Al−Mn (SAM). Another issue that was investigated is the correlation between Ni and Mn content in building materials. The purpose is to observe the best solution for the coating problem of building-used tin alloy powder.

Construction-used ternary powder was the main object in the research and development of EMI shielding materials (thin film). The before−after heat treatment EMI shielding effect and magnetism of SAN and SAM thin film were reviewed to observe the relationship between the characteristics like composition, transparency, conductivity and full-frequent EMI shielding effect. Finally, an overall review and analysis regard to the EMI mechanism and EMI thin film system has been made to bring forward the application of health-care building materials.

Sn−*x*Al−*y*Ni (*x*=40%; *y*=5%, 10%, 15%), Sn−*x*Al−*y*Mn (*x*=40%; *y*=5%, 10%, 15%) and a series of system powders were used in EMI experiment. Polypropylene and Sn−Al−Ni (SAM), Sn−Al−Mn(SAM) system powders were blended (20% of polypropylene) and mixed well in moderation until the system powders were well scattered in polypropylene. The procedure was held by a metal-forming machine. The mixture was then coated on four glass substrates (dimensions of each glass substrate: 2 cm×2 cm×2 cm) and left for 72 h to solidify. The expectation number of coating in the experiment was two or three and the thickness of each coat should be controlled within (20±10) μm. In order to investigate the correlation of EMI shielding effect caused by Sn−Al−Ni and Sn−Al−Mn system, some advanced analysis equipments such as SEM were used to test the particle size and external features of coatings of SAN and SAM, which also helped on the understanding the micro structure of each coating system.

The Elgal set 19A coaxial holder was used for electromagnetic interference shield testing. In this survey, we implemented the coaxial EMI shielding effect apparatus, which is able to scan a large range of frequency area, 300 kHz to 3 GHz, while the accuracy is controlled within 10×10^{-6} (25°±5°). The experiment was conducted by measuring the flat wavelength of perpendicular projection, while the frequency range was controlled between 50 MHz and 3000 MHz. Meanwhile, the results of each measurement were average of 3 to 7 points, and the shielding effective rate was observed by further calculation.

3 Results and discussion

3.1 Effects of Sn−*x*Al−Ni, Sn−*x*Al−Mn coating structure and thin film structure on EMI shielding mechanism

Sn−*x*Al−Ni and Sn−*x*Al−Mn were the main experimental substances and were coated on a glass substrate. An initial coating on surface and analysis on structural properties were done after producing a thin film. At the meantime, another experiment about EMI shielding effect was also done on the thin film and another analysis on structural properties was done to compare the difference before and after heat-treatment. The powder coating experiment shows that under low frequency, even if electric-conductivity declines, the low-frequent EMI shielding effect would still increase as the Al content in Sn−*x*Al coating and stack effect increase. The fractional volume of intermetallic compound in powder would reduce as the Al content reduced as well. This would improve the electrical conductivity of the powder system and hence enhance the EMI shielding effect under high frequency. On the other hand, it has been discovered that a single coating layer would not influence the EMI shielding effect. This is because of the significant result in polypropylene's channel effect. Another result was the three-layered coatings of Sn−*x*Al which would make EMI shielding effect worse. The main reason is that the three-layered coatings would increase the solidified porosity (maximum 15%, volume fraction), and hence, we conclude that the more the layers of coating are, the worse the EMI shielding there will be. On the contrary, a more important discovery in the Sn−Al thin film experiment is that the EMI shielding effective rate would be affected by the thickness of thin film and the electric-conductivity rate. The thicker the thin film and the higher the conductivity rate, the higher the EMI interference effect.

From previous study, we can extend our result to the use of Sn−40Al−15Ni and Sn−40Al−15Mn powders. When the frequency is low, EMI shielding effect could be improved by increasing the Al level in both powders. At the same time, another result in an annealing test shows that with the crystallization under high temperature and high electricity conductivity (Table 1) which could enhance the high-frequent EMI shielding effect of Sn−Al nano thin film as shown in Table 2. Figure 1(a) shows that the spectrum result of the thin film EMI effect experiment on Sn−40Al−15Ni (310 nm), displays the variations of EMI shielding effect (310, 512 and 760 nm) at different as-sputtered levels in Fig. 1(b). Similarly, Table 2 presents the EMI shielding effect.

Table 1 Four-point probe result of Sn alloy

Alloy	Sheet resistance/(10^{-4} Ω·cm)
Sn−40Al−15Ni	1.39
Sn−40Al−15Mn	2.51

Table 2 EMI shielding effect of Sn−40Al−15Ni thin film under different dB values

Film	EMI shield/dB			
	300 MHz	900 MHz	1.80 GHz	3 GHz
310 nm	−11.6711	−14.8100	−13.1616	−17.1193
512 nm	−16.1242	−21.3712	−20.7853	−22.1044
760 nm	−22.3191	−24.0780	−21.3700	−25.7146
310 nm-H	−12.1038	−15.3763	−16.6480	−22.1871

310 nm-H represents the coating heat treated.

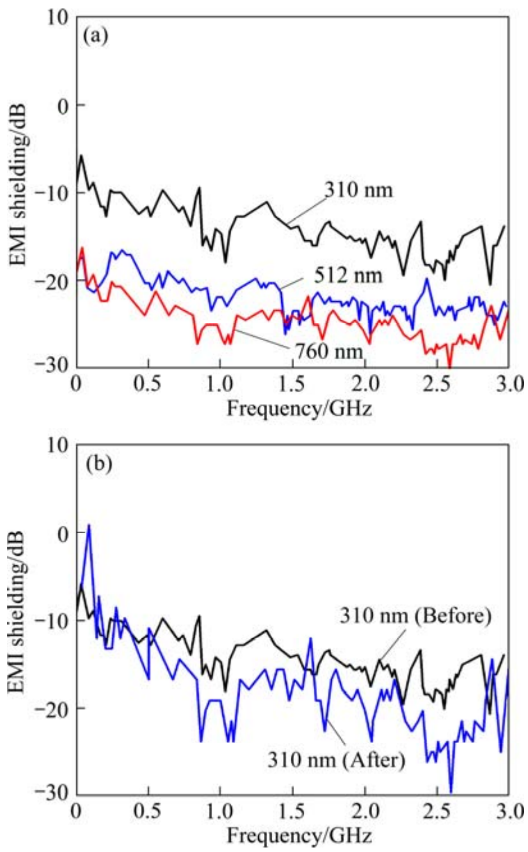

Fig. 1 EMI effect spectra of Sn−40Al−Ni thin film with different thickness (a) and before and after heat treatment (b)

In fact, high as-sputtered level would bring positive result to IOC and hence EMI shielding effect as well. To avoid the influence of particle size, crystallization rate and coating levels, we implemented another annealing test by a 310 nm thin film under vacuum (200 °C, 1 h), and then cooled it down at room temperature (0.5 °C/min). We also tested the EMI shielding effect of 310 nm and (310 nm-H) coatings. After applying annealing tests we then compared these two EMI shielding effects and found that the EMI shielding effect of 310 nm-H thin film is better than 310 nm thin film. Based on these results, we can claim that annealing test (200 °C, 1 h) can not only enhance the conductivity of thin film, but also bring out a better crystallization rate and low resistivity.

Therefore, we believe that annealing test is effective on raising the high frequency EMI shielding effect. However, in terms of the application of building material, the cost of Sn−40Al−15Ni thin film coating is lower than that of Sn−40Al−15Mn, yet the Sn−40Al coating's EMI shielding effect under low frequency is better than under high frequency. Because the electromagnetic environment is usually in low frequency, we decided to apply Sn−40Al−15Ni thin film that is beneficial to EMI shielding effect at the interface layer of building material.

3.2 Sn−40Al−*x*Ni thin film features and EMI shielding mechanism

Tin-based elements have better EMI shielding feature and more advantages in terms of price competitiveness. According to prior study and previous experiments, the amount of Al would affect EMI shielding effect under different frequencies compared with Sn−40Al−*x*Ni thin film, as shown in Fig. 1(a) (x=15%, 40%). Nano-thin film was sputtered on a glass substrate which was constructed by 4 glass substrates. The dimensions of glass substrate were 2 cm×2 cm, as shown in Fig. 2(a), and Sn−40Al coating thickness was between 310 nm and 760 nm (Fig. 2(b)). It is remarkable that applying an annealing test (310 nm-H, 200 °C, 1 h) on Sn−40Al (310 nm) thin film in vacuum would bring a better result in EMI shielding effect, which also shows a

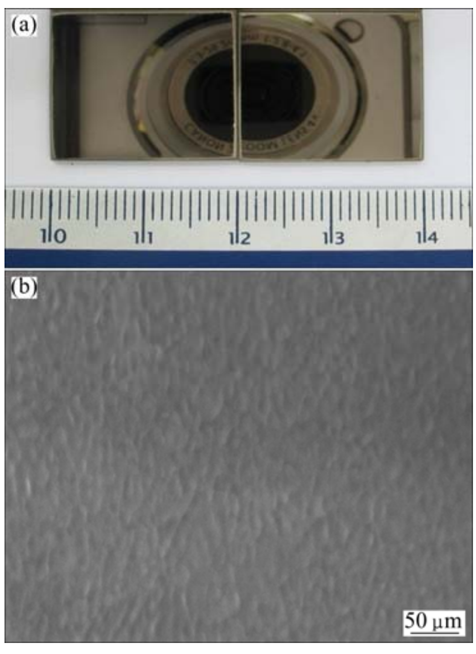

Fig. 2 Characteristics of Sn−40Al−Ni thin film (380 nm): (a) Appearance; (b) Surface characteristic

more detailed appearance on particle surface. This is also one of the reasons for applying hot treatment in order to raise the uniformity.

Because Sn−Al−Mn has a better high-level conductivity (1.08×10^{-4} S/m) and price competitiveness (Table 3), SAN and SAM were used in the experiment of EMI shielding effect. Our prior study shows that high grade of purity in Sn-based materials has the best EMI shielding effect when frequency is 300 kHz−3 GHz. Figure 3 shows the electromagnetic spectra of Sn−40Al−15Mn (710 nm) and Sn−40Al−15Ni (730 nm) thin film. The results show that the EMI shielding effect of Sn−40Al−15Ni (730 nm) thin film is better than Sn−40Al−15Mn (710 nm) thin film as shown in Fig. 3 and Table 4. Sn−40Al−15Mn (710 nm) thin film can partly improve the EMI shielding effect.

Table 3 Four-point probe result of Sn−Al−Ni and Sn−Al−Mn

Specimen	Sheet resistance/(Ω·cm)	
	As-sputtered	Annealed
Sn−40Al−5Ni	6.34×10^{-5}	1.04×10^{-5}
Sn−40Al−5Mn	1.7×10^{-4}	2.8×10^{-5}
Sn−40Al−10Ni	4.41×10^{-5}	2.86×10^{-5}
Sn−40Al−10Mn	4.28×10^{-5}	1.60×10^{-5}
Sn−40Al−15Ni	3.28×10^{-4}	2.01×10^{-4}
Sn−40Al−15Mn	2.44×10^{-5}	7.12×10^{-6}

Table 4 EMI shielding effect of Sn−40Al−Ni and Sn−40Al−Mn thin film under different dB values

Specimen	EMI shielding/dB			
	300 MHz	900 MHz	1.80 GHz	3 GHz
Sn−40Al−5Mn (710 nm)	−12.2984	−17.8346	−21.9801	−15.7783
Sn−40Al−5Mn (710 nm-H)	−6.2322	−7.9891	−14.0344	−15.7527
Sn−40Al−5Ni (380 nm)	−10.6734	−14.8702	−13.2681	−16.3439
Sn−40Al−5Ni (730 nm)	−22.2142	−23.2438	−17.7860	−23.3411

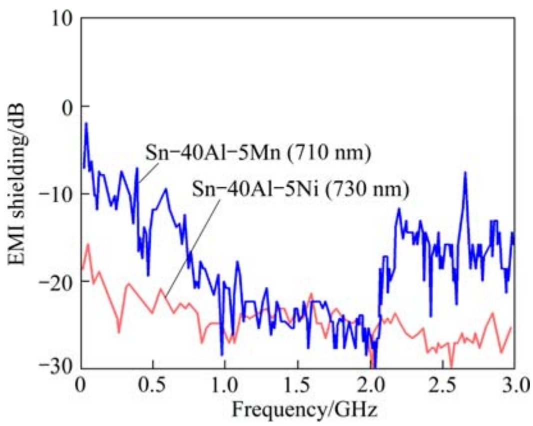

Fig. 3 Electromagnetic spectra for Sn−40Al−5Mn and Sn−40Al−5Ni thin film EMI

The experiment shows that annealed thin film is able to boost conductivity and EMI shielding effect. However, annealed Sn−40Al−15Mn thin film shows a poor EMI shielding effect (compare Fig. 3 and Fig. 4), and the coating thickness of Sn−40Al−15Mn was two times that of Sn−40Al−15Ni, which is very different from the effect of Sn−*x*Al thin film (Fig. 5)). Besides, from the SAM thin film experiment, we can found that there is degeneration in high frequency EMI shielding effect because of the application of annealing test and the increase of volume ratio. The correlation analysis of

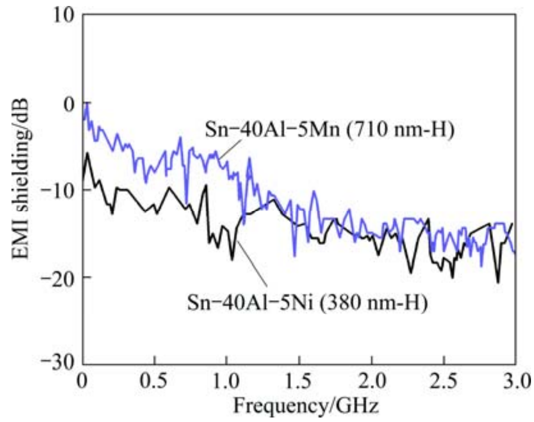

Fig. 4 EMI curves for Sn−40Al−5Mn (annealed) and Sn−40Al−5Ni (un annealed)

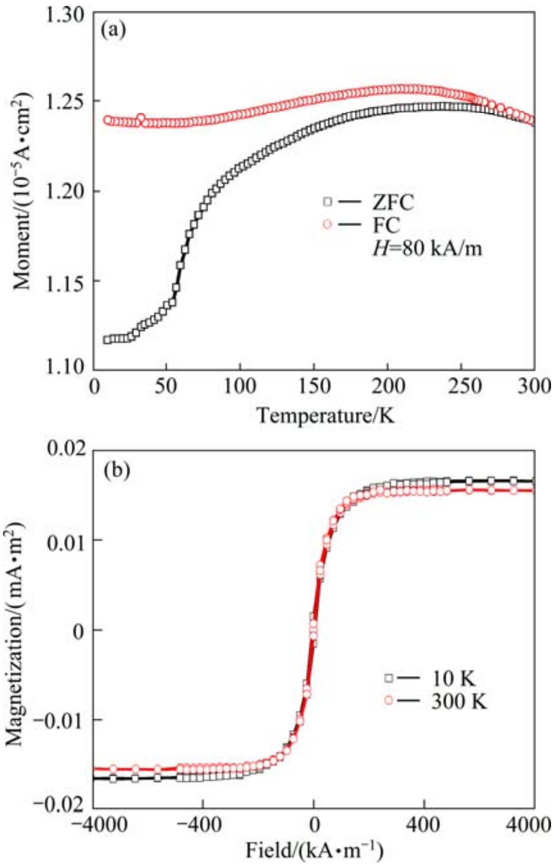

Fig. 5 Quantum magnetic analysis of Sn−40Al−5Ni: (a) Temperature curve; (b) Magnetization

EMI shielding effect of Sn−40Al−Ni (0−5%Ni) powder and thin film shows that the EMI shielding effect of Sn−40Al is significantly improved after the application of annealing test. Note that a high content of Ni would enhance the EMI shielding effect from low to high frequency. Overall, Sn−Al−Ni has a higher conductivity and magnetism, and therefore, it helps a lot on improving the EMI shielding effect.

4 Conclusions

1) By increasing the Al content in Sn−*x*Al−Ni coating, the appearance of stack effect can increase the EMI shielding effect even though conductivity falls. On the contrary, volume fraction of intermetallic compound in powder decreases as the Al content reduces. This will enhance the conductivity and EMI shielding effect under high frequencies.

2) Since the conductivity and magnetism become significant with increasing the Ni content, low frequency EMI shielding effect belongs to high frequent.

Acknowledgments

The authors are grateful to Department of Travel Industry Management, Far East University, NSC 101-2218-E-269 -002 for the financial support.

References

[1] de SIHUES, SILVA M D P J, FERMIN J R. Effect of temperature on the ferromagnetic resonance of Ni50Fe50 thin films [J]. Physica B, 2004, 354(1−4): 361−364.

[2] HONG J I, CHANG Y L, DING Y, WANG Z L, ROBERT L. Snyder, growth of GaN films with controlled out-of-plane texture on Si wafers [J]. Thin Solid Films, 2011, 519(11): 3608−3611.

[3] CHERKASHIN N, KONONCHUK O, REBOH S, HYTCH M. Application of the O-lattice theory for the reconstruction of the high-angle near 90 degrees tilt Si(110)/(001) boundary created by wafer bonding [J]. Acta Materialia, 2012, 60(3): 1161−1173.

[4] YALCIN S, AVCI R. Characterization of PdAu thin films on oxidized silicon wafers: Interdiffusion and reaction [J]. Applied Surface Science, 2003, 214(1−4): 319−337.

[5] YIN K M, CHEN F R, CANG L, KAI J J, CHANG C C, DING P J, CHIN B, ZHANG H, CHEN F S. The effect of oxygen in the annealing ambient on interfacial reactions of Cu/Ta/Si multilayers [J]. Thin Solid Films, 2001, 388(1−2): 15−21.

[6] WOLFFENBUTTEL R F. Low-temperature intermediate Au−Si wafer bonding: Eutectic or silicide bond [J]. Sensors and Actuators A, 1997, 62(1−3): 680−686.

[7] MUSSIG H J, DABROWSKI J, EHWALD K E, GAWORZEWSKI P, HUBER A, LAMBERT U. Can Si(113) wafers be an alternative to Si(001) [J]. Microelectronic Engineering, 2001, 56(1−2): 195−203.

[8] BENOUATTAS N, TAMAARAT B, BOUABELLOU A, HALIMI R, MOSSER A. Electrical properties of Cr/Si(p) structures [J]. Solid-State Electronics, 1999, 43(2): 439−446.

[9] SUEVA D, GEORGIEV S S, NEDEV N, TONEVA A, CHIKOV N. A neutron detector based on an ITO/p-Si structure [J]. Vacuum, 2000, 58(2−3): 308−314.

[10] BIBIC N, MILOSAVLJEVIC M, PERUSKO D, JEYNES C. Investigation of ion beam mixing effects in Ta/Pd bilayers deposited on Si [J]. Thin Solid Films, 1998, 317(1−2): 274−277.

[11] KONDOU R, SUGA T. Si nanoadhesion layer for enhanced SiO_2−SiN wafer bonding [J]. Scripta Materialia, 2011, 65(4): 320−322.

[12] BUTTARD D, EYMERY J, RIEUTORD F, FOURNEL F, LUBBERT D, BAUMBACH T, MORICEAU H. Grazing incidence X-ray studies of twist-bonded Si/Si and Si/SiO_2 interfaces [J]. Physica B, 2000, 283(1−3): 103−107.

[13] WERTHEIMER N, LEEPER E. Electrical wiring configurations and childhood cancer [J]. Am J Epidemiol, 1979, 109(3): 273−284.

[14] UBEDA A, LEAF J, TRILLO M A, DELGADO J M R. J Anat, 1982, 37: 513−536.

[15] LIBOFF A R. Geomagnetic cyclotron resonance in living cells [J]. J Biol Phys, 1985, 13: 99−102.

[16] PAINE D C, WHITSON T, JANIAC D, BERESFORD R, YANG C. A study of low temperature crystallization of amorphous thin film indium–tin–oxide [J]. J Appl Phys: Sci Eng, 1999, A85: 12−15.

[17] LIU D, SUQIAO D. Asia-pacific conference on environmental electromagnetics. 2000, 6: 326−332.

[18] VOSSEN J L. Transparent conducting films [J]. Phys Thin Films, 1997, 9: 1−71.

[19] HUNG F S, HUNG F Y, CHIANG C M, LUI T S. Effects of the Sn−Al and Sn−Cu Thin films on the electromagnetic interference shielding for the advanced materials [J]. Transactions of Nonferrous Metals Society of China, 2011, 21(9): 2020−2025.

镍和锰的添加对建筑材料 Sn 基纳米薄膜电磁屏蔽性能的影响

洪飞硕

远东科技大学 旅游事业管理系，台南，台湾

摘　要：世界卫生组织已证明电磁波对公众健康会带来危害。然而，最近的相关建材与电磁波联系的研究主要集中在电磁产品上。生态环境更强调新产品的开发和无害环境。这些研究没有涉及健康保健、生活材料方面，尤其是那些大块高透明材料。因此，尝试向 Sn 基粉末中添加 Ni 和 Mg 而使材料具有电磁屏蔽性能。因其低费用的优势，建材使用此类三元系材料，即 Sn−Al−Ni(SAN)，Sn−Al−Mn(SAM)。研究了采用表面包覆方法时，粉末尺寸、Ni 与 Mn 的比例、烟囱效应、孔隙度和厚度对材料屏蔽性能的影响机制。

关键词：镍；锰；电磁屏蔽

(Edited by Xiang-qun LI)