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Current Status of Soft Ferrite in Japan

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Abstract. This paper focuses on recent developments in the field of materials technology of soft ferrites in Japan. With the rapid development of the electronics market, the ferrite industry has grown to a considerable size. Magnetic characteristics of ferrites are quite sensitive to the chemical composition, the production process and to microstructure. Controlling these factors is an important key to achieving high performance ferrites. MnZn ferrites are classified according to their characteristics. High initial permeability materials are used for wide band and pulse transformers, and low power loss materials are used for power application. High initial permeability, over 20000 at 10kHz, was achieved by Bi₂O₃ addition using high purity raw materials. Low loss MnZn ferrite, with P_{cv}=199kW/m³ at 100kHz, has recently been developed by SnO₂ addition under some optimized process conditions. NiCuZn ferrite is employed for multilayer-ferrite chip-components (MLFC). Low oxygen partial pressure during sintering is an important factor in controlling the nanostructure of grain boundaries. MnMgZn ferrite has been produced in large quantity for deflection yoke application because of its high cost performance. Investigation of composition, additives and sintering conditions has made it possible to obtain lower loss than that in NiCuZn ferrite measured at higher temperatures.

1. INTRODUCTION

Since the discovery of an efficient mixed ferrite by Dr. Yogoro Kato and Dr. Takeshi Takei about 60 years ago [1], much basic and applied research and development has been carried out in Europe as well as in Japan. In the 1940's and 1950's, ferrites were systematized in the academic field, and today ferrite theory is well organized. In 1935, Japan pioneered the mass-production of ferrites. From the 1950's, as radio and television sets spread, ferrites established a significant position in industry, and now ferrites are one of the most essential materials in the electronics industry.

Soft ferrites are widely used in electronic devices as magnetic cores for high frequency applications. The advantages of ferrites for these applications are higher electronic resistivity as opposed to metals, high machinability, ease of die pressing, chemical stability and lower cost. Figure. 1 shows the average monthly sales of soft magnetic ferrite cores in Japan in the last seven years, which were taken from the Electronic Materials Manufacture's Association of Japan. The sales for the year of 1991 declined slightly on account of the business recession over the world. However, after that, the ferrite business has been improved stably. Sales of soft ferrites, shown in Fig. 1, have been classified by fields of application in Fig. 2. In spite of a recent stability in the overall market, the sales in deflection yoke and power applications have grown gradually. The former has been supported by sales of CRTs (Cathode Ray Tube) for personal computer and television sets for home use, while the latter is due to switching power supply.

Various performance characteristics of ferrites are necessary for varied applications. However, basically high permeability, high saturation magnetization, high Curie temperature, and low loss are expected. It is impossible for one type of ferrite to possess all of these at once, and the type of ferrite should be chosen depending on what performance characteristic is important. In the following sections, the review of recent developments in the field of materials technology of soft ferrites is described.

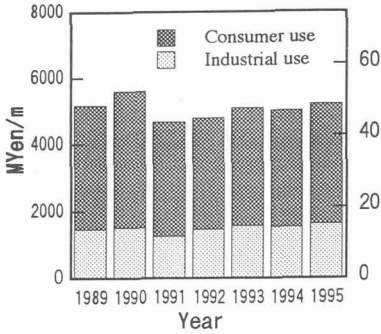


Fig.1 Average monthly sales of soft ferrite in Japan.

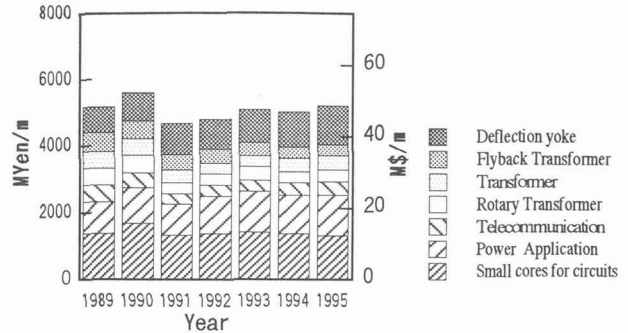


Fig.2 Sales of soft ferrite classified by fields of application.

2. High initial permeability MnZn ferrite

High initial permeability MnZn ferrites are mainly used in devices for telecommunication applications such as the pulse transformer. For high initial permeability, some technological innovations have been applied [2-5]. One is compositional choice for small magnetocrystalline anisotropy constant and magnetostrictive constant. The other is high mobility of domain wall by inducing low residual stress and controlling microstructure, grain size, and defects.

The temperature dependence of initial permeability of Bi₂O₃ added specimens are shown in Fig.3. High permeability MnZn ferrites, with $\mu_i = 23000$ and $\tan \delta / \mu_i = 10 \times 10^{-6}$ at 10kHz, have been developed by optimization of compositions and sintering process conditions. Grain growth is thought to result from Bi₂O₃ addition to MnZn ferrite [6]. However, the experimental results are substantially different [7]. Thus, the high permeability should be explained by an effect other than Bi₂O₃ addition. The compositional distributions near grain boundaries are shown in Fig.4. The Bismuth content dependence on the δ value is shown in Fig.5, representing oxygen content in the sintered body. Smaller δ value deviations were obtained for Bi₂O₃ added specimens rather than those of specimens without Bi₂O₃. It is assumed that Bi promotes diffusion mobility of O₂ through grain boundaries. High initial permeability is therefore thought to be due to the homogeneous oxygen content distribution in the sintered body, facilitated by high diffusion mobility.

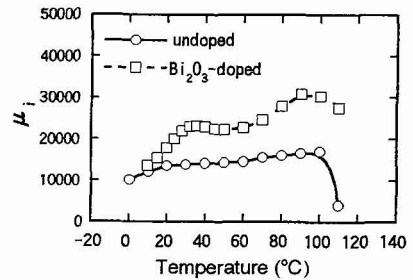


Fig.3 Temperature dependence of initial permeability of Bi₂O₃ added high μ_i MnZn ferrites.

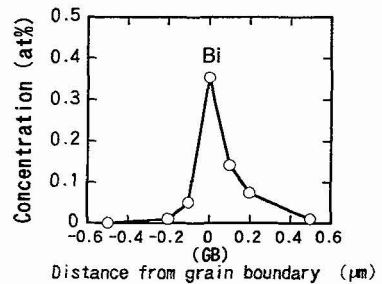


Fig.4 Distribution near grain boundaries of Bi₂O₃ of MnZn ferrite samples.

3. Low power-loss MnZn ferrite

Low power-loss MnZn ferrite is widely used for power application such as the switched-mode power converter. Power loss is theoretically divided into hysteresis, eddy current, and residual losses [8]. These three functions are distinguished from each other according to the difference in their frequency dependencies. Eddy current loss is proportional to the reciprocal of electrical resistivity. High electrical resistivity is one of the most important characteristics for the power ferrite. This characteristic has been improved mainly by adequate additives [9]. It is well known that the addition of CaO and SiO₂ in MnZn ferrite is effective in raising the electrical resistivity through the formation of an insulating layer along the grain boundaries. In order to achieve lower loss characteristics, high resistivity in the main phase has been required.

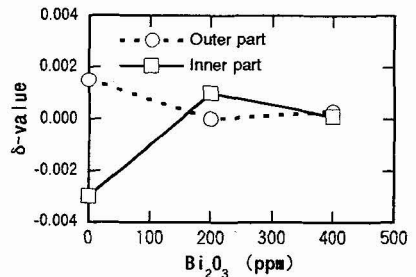


Fig.5 Effect of Bi₂O₃ doping on the δ -value.

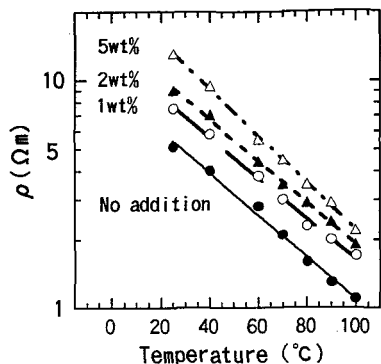


Fig. 6 Temperature dependence of dc resistivity as a function of SnO₂.

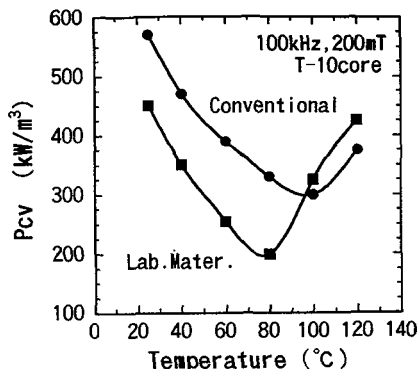


Fig. 7 Temperature dependence of power loss of MnZn ferrite.

SnO₂ is well known to be soluble in spinel [10] and to compensate for Fe²⁺. Figure.6 shows the temperature dependence of dc resistivity as a function of SnO₂ content. Addition of SnO₂ to MnZn ferrite was effective in controlling the electron transfer between Fe²⁺ and Fe³⁺, and consequently increased the resistivity. As a result, low loss MnZn ferrite, P_{cv}=199kW/m³ (100kHz, 200mT, 80°C), has been recently developed by SnO₂ addition under some selected process conditions, as is shown in Fig.7 [11].

4. NiCuZn ferrite

NiCuZn ferrite is employed for multilayer-ferrite chip-components (MLFC), because of its high performance at high frequencies. The sintering temperature of NiCuZn ferrite for MLFC should be below 900°C to avoid melting the internal Ag winding. Nakano, et. al. [12,13] reported that Ag introduced a compressive residual stress by diffusing into the ferrite, which was observed as interference fringes at grain boundaries by TEM. Recently, in order to achieve high frequency and high performance MLFC, other additives have been studied [14]. Figure.8 illustrates the effect of impurities on the Q-factor of a chip inductor. Addition of CoO was effective in improving the Q-factor to a maximum amount of 2000-3000 ppm, while other impurities degraded it. Sintering conditions are also an important factor. High purity of raw materials for NiCuZn ferrite are essential to MLFC. The effect of oxygen partial pressure during sintering on dc resistivity is shown in Fig.9. Low oxygen partial pressure, such as 5% oxygen, led to high dc resistivity and high Q-factor because of the decreasing residual stress (manifested as a reduction in interference fringes).

Production of multilayer-ferrite chip-components has grown remarkably in past years. To enhance the performance of MLFC, it is of prime importance to control the small amount of ingredients and the firing conditions, as well as to control the stress caused by internal Ag winding. New progress in MLFC can be expected using such material technology.

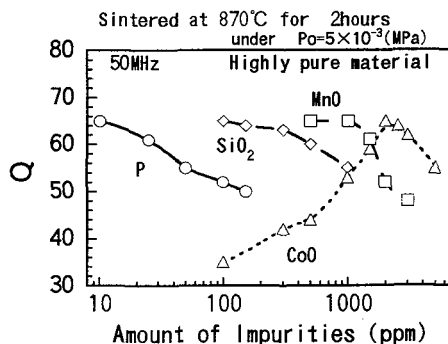


Fig. 8 Effect of impurities on the Q-factor of chip inductor.

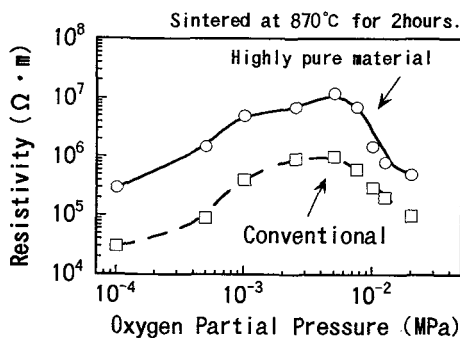


Fig. 9 Effect of Po₂ on the dc resistivity of NiCuZn ferrite.

5. MnMgZn ferrite

MnMgZn ferrites have been produced in large quantity for deflection yoke application because of its high cost performance. Recently, wider screen and high definition television for home use and high definition PC display have been in high demand. Higher performance of ferrite materials for deflection yokes are necessary to match such demand. High saturation magnetization and low loss, as well as small shape tolerance, are important properties for ferrites for deflection yokes [15]. In Fig.10, the temperature dependence of power loss of low loss MnMgZn ferrite is shown [16]. Investigation of composition, additives and sintering conditions have made it possible to obtain lower loss than that in NiCuZn ferrite at higher temperatures. Smaller magnetocrystalline anisotropy achieved by optimizing the oxidation grade of metal ions [17], and higher resistivity of the grain and grain boundaries, by the control of microstructure, are thought to be the main factors yielding low loss.

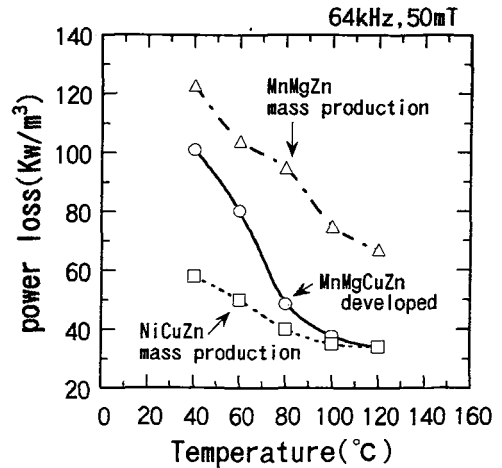


Fig.10 Temperature dependence of power loss of MnMgZn ferrite.

6. CONCLUDING REMARKS

There is no doubt that the ferrites market will grow steadily as magnetic materials for high frequency devices. No alternative materials are projected for the future. In addition, higher electronic and magnetic properties for ferrites have been demanded, corresponding to the electronic industry pursuing smaller and higher performance electronic devices. For high performance ferrites, control of microstructures as well as grain boundaries is necessary. Among the many ferrite production process factors, purity of raw materials, additives and sintering process should be well optimized. As the latest process for ferrites production, the co-spray roasting method has been industrialized. High purity ferrites are obtained from relatively low cost raw materials with high impurity content through this excellent process. And more advanced technology for structural analysis, definitive composition analysis and performance evaluation at high frequency are essential for the next generation of ferrites.

After the passing of sixty years of ferrite history, it is generally believed that the growth stage had finished and that the maturity stage has started. However, new applications of ferrites, such as toners and ferrite carrier for photocopy machines and the application of biotechnology, have been developing. I believe that much high performance and high dependability of ferrites will be achieved through new materials process and microstructure control technology based on our exciting technology and theory.

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