Application of lead alkali–silicate bonding glass to ferrite heads

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The residual stress induced in the bonding glass bonded to a ferrite substrate was measured with a photoelastic method. The permeability and the head output showed a maximum at a specific compressive stress. This behaviour was explained by the change of induced anisotropy caused by the magnetoelastic effect.

1. Introduction

Single-crystal Mn–Zn ferrites are applied to VCR and computer disk heads. A typical structure of a ferrite head is shown in Fig. 1. The gap is filled with glass of high melting temperature and the two cores are combined with each other by using bonding glass.

The bonding glass must match the thermal expansion of the ferrite and have a working temperature below 900° C [1]. A lead alkali–silicate composition serves well for the bonding glass [2], so that the other glass cannot react extensively with it.

Kugimiya [3] has reported that the magnetic properties of the ferrite head are deteriorated by microcracks, heavy crystal defects, Beilby layer formation, etc. during the head fabrication process. He also reported that a mismatch of thermal expansion coefficient between the ferrite and the glass caused head deterioration but the relationship between the residual stress in the glass and the mismatch behaviour was not clarified.

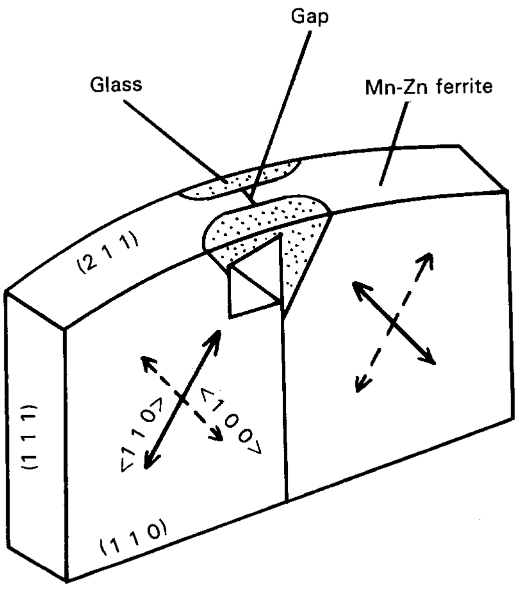

Figure 1 Typical structure of ferrite head: ( ) means crystal direction and ⟨ ⟩ magnetization axis direction.

In this paper, the effect of the residual stress in the bonding glass on the magnetic performance of the ferrite head was studied by using a photoelastic method [4].

2. Experimental procedure

2.1. Fabrication of ferrite–glass composite core

The composition of the single-crystal Mn–Zn ferrite studied was 54.5 mol % Fe_2O_3, 27 mol % MnO and 18.5 mol % ZnO. It had a thermal expansion coefficient of $114 \times 10^{-7}\,°C^{-1}$ in the temperature range 30–400 °C. The bonding glasses studied had a thermal expansion coefficient of $91–129 \times 10^{-7}\,°C^{-1}$ in the temperature range of 30 °C to T_g, the glass transition point. Table I shows the compositions of the bonding glasses studied. The raw materials were SiO_2, Pb_3O_4, ZnO, Na_2CO_3, K_2CO_3, Li_2CO_3 and As_2O_3 of reagent grade. The batches were melted at temperatures in the range 1300–1400 °C in a platinum crucible. The melting time was 60 min in air. The melts were rapidly quenched with the aid of a twin roller technique. The thermal expansion coefficient α and the transition point T_g were dilatometrically determined at a heating rate of $10\,°C\,min^{-1}$ with a Rigaku 8140 thermomechanical analyser. The glasses B and C were prepared by mixing glasses A and D, and the glasses E and F from D and H.

TABLE I Compositions (wt %) of the bonding glasses studied

	A	B	C	D	E	F	G	H	I	J
SiO_2	40			34			30	36	36	39
PbO	50			55			60	52	51	44
ZnO	5			5			5	5	5	2
Na_2O	4			4			4	5	5	5
K_2O	1			1			1	3	4	8
Li_2O										1
As_2O_3										1
$\alpha (\times 10^{-7}\,°C^{-1})$	91	101	102	102	108	107	106	111	117	129
T_g(°C)	448	408	428	424	405	419	414	418	412	398

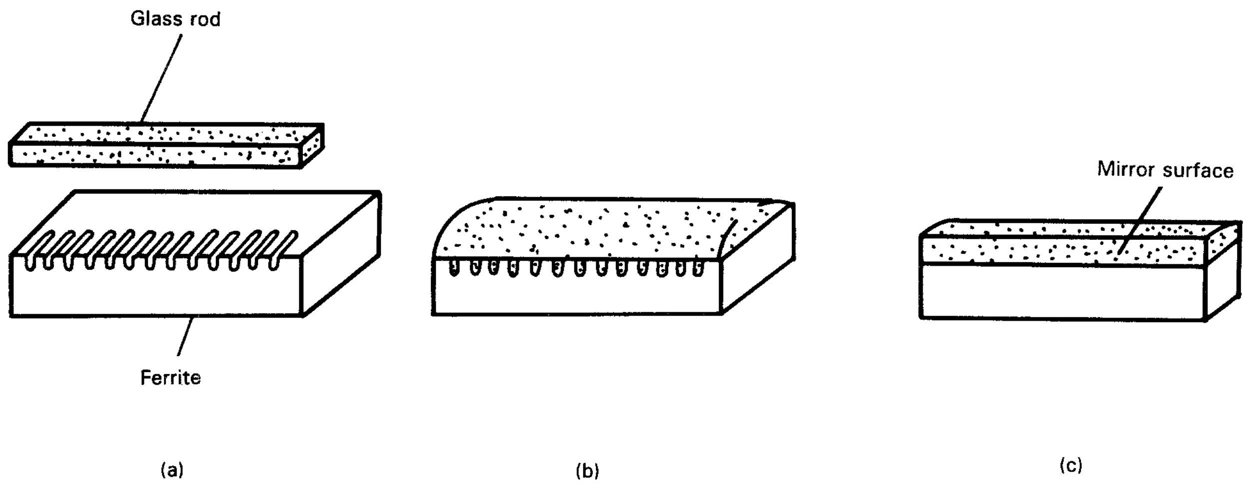

Figure 2 Process of fabricating the ferrite–glass composite core to measure stress.

Fig. 2 shows the process for fabricating the ferrite–glass composite core. A glass rod of 0.8 mm × 0.8 mm × 27 mm is cast on a ferrite substrate of 2.6 mm × 1.6 mm × 25 mm at 750 °C for 30 min in a nitrogen atmosphere. After casting, the composite was cooled in a furnace to room temperature. Both sides of the composite were ground and polished to make mirror surfaces smooth enough for visible light to pass through the glass.

2.2. Measurement of residual stress

The residual stress induced in the bonding glass was measured with an SVP30-2 polariscope (Toshiba Glass Ltd). The stress F (kg cm^{-2}) was calculated from the equation

$$F = \delta / Cd \tag{1}$$

where δ (nm) is the optical path difference, C the photoelastic constant and d (cm) the thickness of the bonding glass. Since the bonding glasses contained about 50 wt % PbO, 3.0 was used for C to calculate the stress [4].

2.3. Measurement of permeability

Ferrite rings of external diameter 5 mm, internal diameter 3 mm and thickness 0.2 mm were prepared by polishing with 4000 mesh SiC abrasives. After polishing, the ferrite rings were etched in phosphoric acid at 80 °C for 4 min to remove the residual stress caused by machining processes.

Glass rings of the same size were bonded to the ferrite rings at 690 °C for 30 min in a nitrogen atmosphere. After bonding, these toroidal samples were cooled in the furnace to room temperature.

The permeability of the toroidal samples was measured with a Yokogawa–Hewlett-Packard 4193A vector impedance meter at room temperature.

2.4. Measurement of magnetic performance of head

Video head output levels were measured under the condition that S-VHS type video heads with a track width 49 μm and a gap length 0.3 μm were fixed at a bench, and S-VHS tape rubbed past the heads at a relative speed of 5.8 m s^{-1}. The head fabrication process is described elsewhere [5].

3. Results and discussion

Fig. 3 shows the dependence of the induced stress in the glasses on the thermal expansion coefficient of the bonding glass. A compressive stress was induced in glasses A to I and a tensile stress in glass J. In the case of glass A, the fracture of ferrite was observed. This phenomenon must be attributed to the large tensile stress in the ferrite.

Fig. 4 shows typical colours in strained glasses when observed in the polariscope with a crossed tint plate. Glass F is shown in compression in Fig. 4a, and glass J in tension in Fig. 4b.

It is well known that the compressive strength of glass is about ten times larger than the tensile strength [6]. This rule also applies to the bonding glass [7]. Therefore glasses B to H were selected to fabricate the toroidal samples and the video head.

Fig. 5 shows the effect of compressive stress on the permeability. The permeability showed a maximum at a compressive stress of 120 to 140 kg cm^{-2} in the bonding glass.

Fig. 6 shows the effect of compressive stress on the head output. The output was normalized to the result for the head with glass D. It showed a maximum at a compressive stress of 120 to 140 kg cm^{-2} in the bonding glass. The maximum point of the head output coincides with that of the permeability of the ferrite. It must be noted that the same order of tensile stress is induced in the ferrite. This behaviour is explained by the change of induced anisotropy caused by the magnetoelastic effect [8]. As the ferrite has a negative magnetostriction, $\lambda_{100} < 0$ [9], when a positive tensile stress $F > 0$ is applied, the sign of $\lambda \times F$ will be negative. While a hard axis is induced in the $\langle 100 \rangle$ direction, an easy axis is induced in the $\langle 110 \rangle$ direction. Consequently, the gap is placed between the two easy axes in either core as shown in Fig. 1. Since this

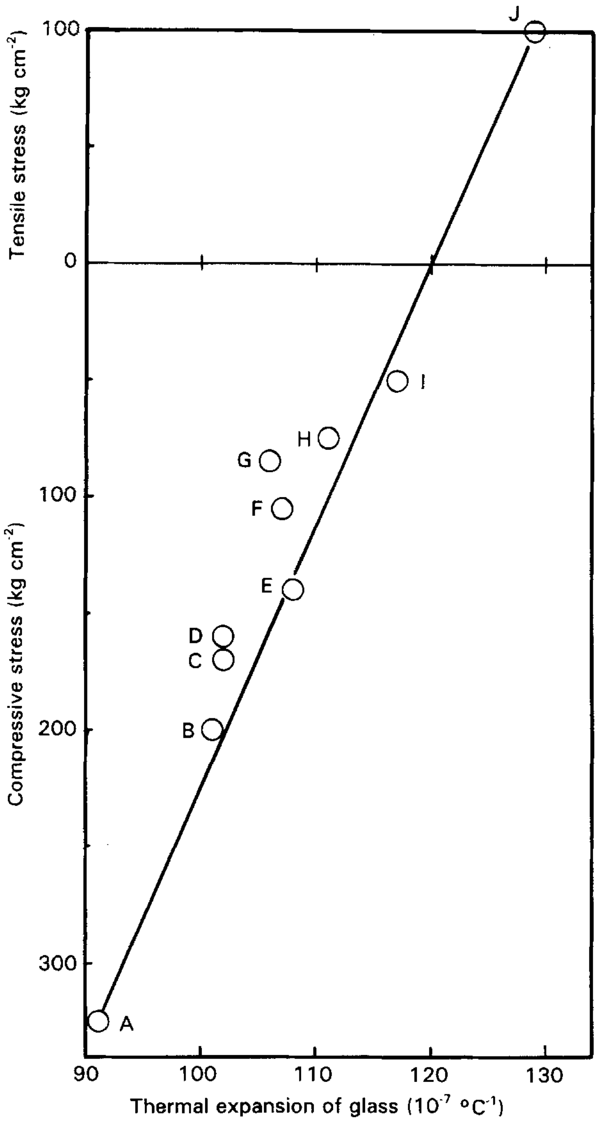

Figure 3 Dependence of induced stress on the thermal expansion coefficient of the glasses. Letters A to J correspond to the glasses in Table I.

condition coincides with the most favourable magnetization axis direction reported by Kugimiya [3], the head output will have a maximum here.

4. Conclusions

1. When glasses with a thermal expansion coefficient of $91\text{–}129 \times 10^{-7}\,°C^{-1}$ are bonded to ferrite with a coefficient of $114 \times 10^{-7}\,°C^{-1}$, a compressive stress is induced in the glasses with coefficients of 91–117 $\times 10^{-7}\,°C^{-1}$.

2. The permeability of the toroidal samples showed a maximum at a compressive stress of 120 to 140 $kg\,cm^{-2}$ in the bonding glass.

3. The head output also showed a maximum at a compressive stress of 120 to 140 $kg\,cm^{-2}$ in the bonding glass.

4. The maximum point of the head output coincides with that of the permeability of the ferrite.

Our future investigations will endeavour to throw light on the case of a metal-in-gap head with low-melting bonding glass [10,11].

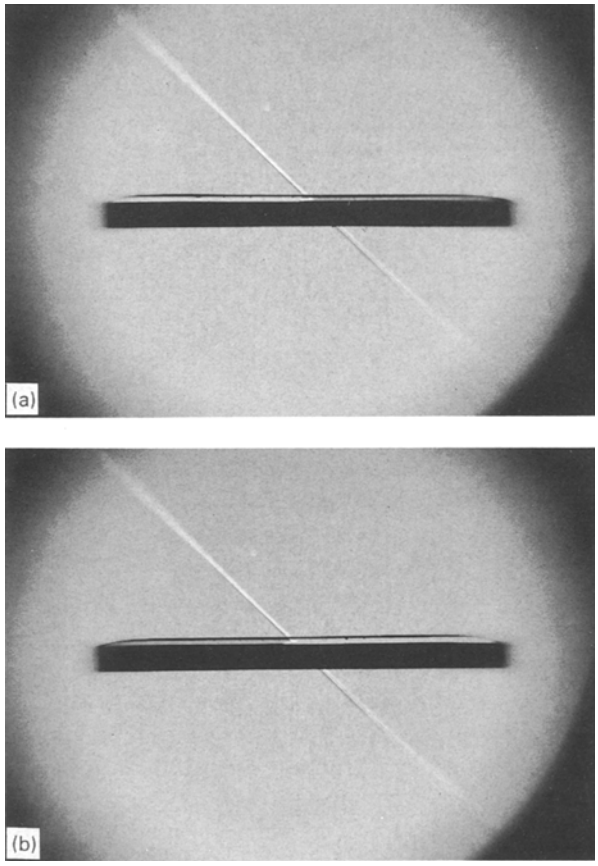

Figure 4 Colours in strained glasses when observed in the polariscope with a crossed tint plate.

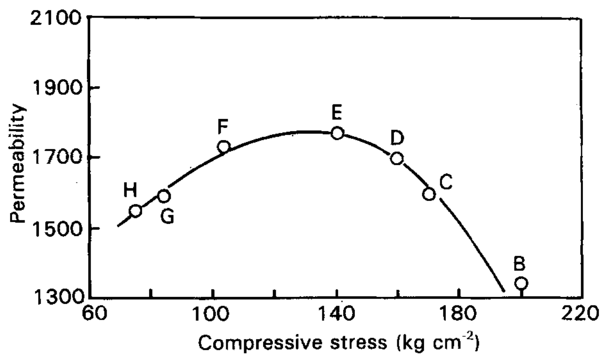

Figure 5 Effect of compressive stress on permeability at 0.5 MHz.

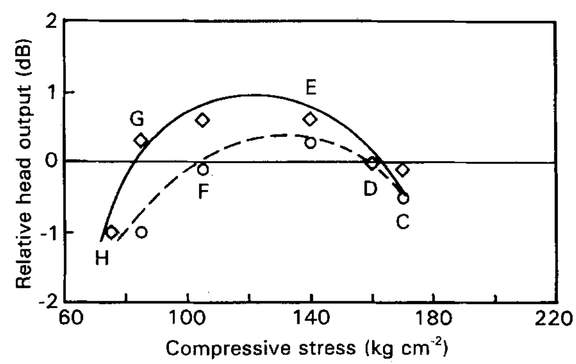

Figure 6 Effect of compressive stress on relative head output: (○) 0.5 MHz, (◇) 7 MHz.

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References
1. R. R. TUMMALA, in "Glasses for Electronic Applications", edited by K. M. Nair (American Ceramic Society, OH, 1991) p. 424.
2. T. HIKINO and M. MIKODA, Japanese Patent Application "Kokai" (Laid-open) Nos 50–32 210 and 50–32 211 (1975).
3. K. KUGIMIYA, *Amer Ceram. Soc. Bull.* **69** (1991) 696.
4. F. V. TOOLEY, in "The Handbook of Glass Manufacture", Vol. 2 (Books for Industry, New York, 1974) p. 903.
5. Y. MIZUNO, A. NISHINO, M. IKEDA and S. KURIO, US Patent 4 855 261 (1989).
6. G. W. MOREY, "The Properties of Glass" (Reinhold, New York, 1954) p. 333.
7. Y. MIZUNO, *New Glass* **6** (New Glass Forum, Tokyo (1991) p. 258.
8. S. KUMAGAI, Y. IKEDA and M. HAYAKAWA, in digests of the 6th International Conference on Ferrites, Tokyo, September 1992 (Japan Society of Powder and Powder Metallurgy) p. 449.
9. K. OHTA, *J. Phys. Soc. Jpn* **18** (1963) 685.
10. Y. MIZUNO and M. IKEDA, *J. Ceram. Soc. Jpn Intnl Ed.* **100** (1992) 85.
11. Y. MIZUNO, M. IKEDA and A. YOSHIDA, *J. Mater. Sci. Lett.* **11** (1992) 1653.

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