High Verdet constant Faraday rotator glasses

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ABSTRACT

Faraday rotator glasses with high Verdet constants are used for optical isolators and sensors. Based on Tb_2O_3 -B_2O_3-Al_2O_3-SiO_2 system and the effect of each component on glass formation, glass compositions were selected for development of new Faraday rotator glasses. Devitrification of Tb-glass was studied by microscopic morphology to establish the production process. Dispersion of Verdet constant and the influence of Tb^{3+} concentration on Verdet constant were investigated. Special technology was utilized for production of platinum-free glass. Quenching process is necessary to obtain crystal-free glass. Three kinds of Faraday rotator glass with high Verdet constant than that of M16 have been developed. The higher Verdet constant glass is possible to obtain.

1. INTRODUCTION

Faraday rotator glass materiales are used for optical rotators, modulators and fast optical switches. Various crystal , such as terbium alumium garnet, terbium gallium garnet were developed. Glass materials are of interest for optical applications because glass composion can be widely changed to contain large concentration of specific oxides to meet the demands in optical effects.

In high power laser systems, optical isolators are necessary to prevent the distruction of laser disks or other optical components caused by reflected laser from target. Large aperture Faraday rotator glass with high Verdet constant is used as rotator material to obtain large rotation angle of linearly polarized laser form the given length of glass at low intensity of magnetic field.

Paramagnetic glasses containing Ce^{3+}, Tb^{3+} , Dy^{3+} or Eu^{3+} with large effective magneton values or inherent absorptions in near ultraviolet region show high Verdet constants. Cerium phosphate glass, FR4, with a medium Verdet constant was produced by Hoya. The commercial high Verdet constant Tb-Faraday rotator glasses M16 from Kigre, Inc. and FR5 from Hoya have been produced for years. In this paper , the new Faraday rotator glasses with much higher Verdet constants than that of M16 are developed.

2. GLASS COMPOSITION SELECTION AND TECHNOLOGY

There are many patents on high rare earth content glasses based on binary borate, phosphate, silicate and germanate. Because of high electric field strength of rare earth ions, these ions will attract glass forming cation-oxygen tetrahedra to form coordination polyhedra. RE_2O_3-$SiO_2$and RE_2O_3-B_2O_3systems have a strong tendency of crystallization or liquid-liquid seperation. The first practical composition system for high rare earth oxide content glasses was RE_2O_3 -Al_2O_3-SiO_2 system reported by Robinson and Graft[1]. Introduction of aluminium

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oxide will expand glass formation region. Magneto-optical properties of this system were investigated by Kohli and Shelby[2,3] recently. Tb_2O_3-B_2O_3-Al_2O_3-SiO_2 system was chosen for the development of new Faraday rotator glasses. The following were considered in choosing glass composition. High Tb^{3+} concentration to increase Verdet constant; low network modifier content to prevent distruction of glass network; high intermediate content to connect the broken glass network; high B_2O_3 content to improve technological performance. Three compositions with Tb^{3+} concentration from 7.9 x 10^{21} to 11 x 10^{21} ions per cc have been determined.

Highly pure materials with iron oxide content less than 3ppm, and Tb_2O_3 of 99.99% Tb_2O_3/RE_2O_3 were used to decrease optical loss. The technology for manufacturing platinum-free laser glass developed by Kigre, Inc. was used for production of Faraday rotator glasses. Glass batch was premelted in ceramic crucible. Rifine and cooling were carried out in a platinum melting system with atmosphere protecting to provent formation of platinum particles. High efficient stirror was used to homogenize glass melt. Large cooling rate from forming temperatue to annealing temperature will be necessary for high Tb^{3+} concentration glass to produce crystal-free and homogeneous glass.

3. PHYSICAL PROPERTIES OF GLASSES

Physical properties of three kinds of new Faraday rotator glasses, M18, M24 and M32 are listed in table 1. Most properties were measured at Kigre. Verdet constants at different wavelengths were measured by ISOWAVE.

Table 1. Physical properties of Faraday rotator glasses

	M18	M24	M3
Verdet constant V (Rad/T.m)			
at 1064nm	- 20.59	- 26.1	- 29.0
632nm	- 74.76	- 88.16	- 98.40
Refractive index n	1.6818	1.7009	1.7275
Abbe number	48.81	52.23	51.37
Non-linear index n_2(10 e.s.u.)	2.7	2.6	2.9
Attenuation coefficient (cm^{-1})			
at 1060nm	<0.001	<0.001	<0.001
Density (g/cm^3)	4.331	4.450	4.850
Coefficient of expansion (10^{-7}/ °C)	56.3	55.9	60.0
Transformation Temp. (°C)	757	775	774
Deformation temp. (°C)	799	810	810
Knoop hardness (N/mm^2)	7380	7500	7930
Young's modulus E (10^3 N/mm^2)	113.4	121.0	120.2
Rigidity modulus G (10^3 N/mm^2)	42.4	45.6	46.0
Poission's ratio	0.339	0.326	0.306

4. DISCUSSION

4.1. Dispersion of Verdet constant

Dispersion of Verdet constant of materials containing paramagnetic rare earth ions can be expressed by well known equation derived by Van Vleck and Hebb.

$$V = \frac{4\ ^2\mu_B v^2}{3chKT} \frac{Np}{g} \sum \frac{C_n}{v^2 - v_n^2} \quad (1)$$

where μ_B is the Bohr magneton, N is the concentration of paramagnetic ions per unit volume, p is the effective magneton, v is the frequency of light, v_n is the absorption frequency, C_n is the transfer probability at v_n, c, K and T have their usual meaning. Σ term are the contribution of each absorption to the dispersion. The inherent absorption of Tb^{3+} in 200-300nm dominates the dispersion of Verdet constant in visible and near IR region. Eq.(1) can be rewrited as Eq.(2) for a specific glass.

$$\frac{1}{V} = K \left(1 - \frac{\lambda^2}{\lambda_n^2} \right) \quad (2)$$

where, λ and λ_n are the wavelength of light and inherent absorption respectively. The reciprocal of Verdet constant will be proportional to square wavelength. Extending the straight line to 1/V=0, the wavelength of inherent absorption can be obtained. Determined wavelength of inherent absorption are 254nm and 261nm for M18 and M24 respectively.

Dispertion of refractive index is principally determined by the absorption at ultraviolet region. The absorption wavelength can be calculated from measured refractive indeces at different wavelengths by simplied dispersion formula[4]. All the calculated wavelengths of absorption of M18, M24 and M32 are 153nm.The absorption is considered to be inherent absorption caused by bonds of non-bridge oxygen-silicon or modifying ions. It can be understanded that the dispersions of different physical properties arise from different inherent absorptions.

4.2. Devitrification of Tb-glass

High Tb_2O_3 content glass has a strong tendency to devitrification. Fig.1 shows an optical micrograph of M18 glass heat-treatmented at 900°C for 30 mins, and Fig.2, the same glass heat-treatmented at 980°C for the same time. Devitrification of M18 glass occurs by liquid-liquid seperation first and then crystallization in one of the seperated phase.

Fig.1. micrograph of liquid-liquid seperated M18 glass, heat-treatmented at 900°C, 30 mins, magnified 200x.

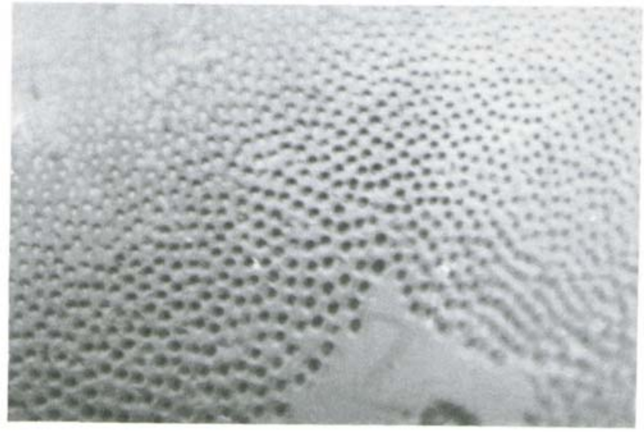
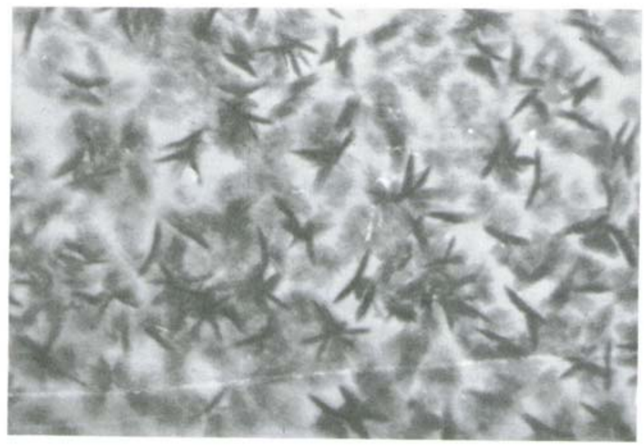


Fig.2. Micrograph of crystallized M18 glass, heat-treatmented at 980°C, 30 mins. magnified 200x.



4.3. Tb^{3+} concentration and Verdet constant

The relation between Verdet constants at 1060nm and Tb^{3+} concentrations was summaried in Fig.3. A roughly linear relationship for most vitreous and crystalline materials shows that the Verdet constant is principally determined on the concentration of Tb though these materials have different inherent absorption wavelengths and transition probabilities,[21] As Tb^{3+} concentration increased from 8.0×10^{21} ions/cc for M18 to 10.4×10^{21} ions/cc for M32, Verdet constant at 1060nm increased from 74.8 to 98.4 Rad/T.m. Compare with the widly used crystal Terbium Gallium Garnet (TGG) with a Verdet constant of 134 Rad/T.m, the Verdet constant raised from 64% of that of TGG for M18 and to 84% for M32. Glass with a Tb concentration of 12 x 10 ions/cc, which is 93% of that in TGG, is estimated to be available.

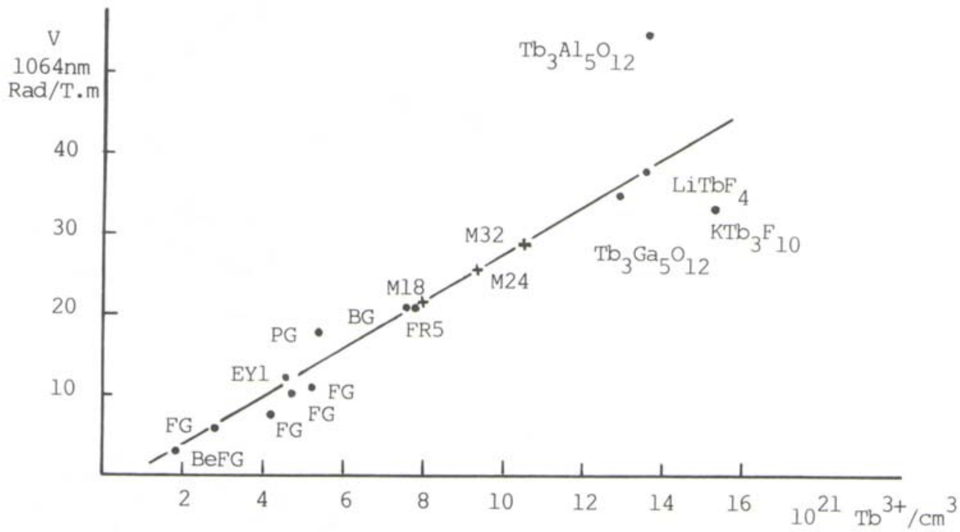


Fig.3. Relationship of Tb^{3+} concentration to Verdet costant

5.CONCLUSION

Based on Tb_2O_3-B_2O_3-Al_2O_3-SiO_2 system, three kinds of Faraday rotator glasses with much higher Verdet constants than that of commercial Tb-glasses have been studied and developed. Compared dispersion of Verdet constant with that of refractive index, the dispersions of different physical properties are caused by different inherent absorptions is found. Devitrification process of high Tb_2O_3 content glass was determined to be liquid-liquid seperation and then crystallization. The glass with a higher Tb^{3+} concentration than that of Faraday rotator glasses reported in this paper, near to that of TGG, would be available.

6. REFERENCE

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