

Synthesis and Magneto-Optical Performance of a Terbium-Based Hybrid Glass

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Abstract

Rare-earth-doped glasses have attracted sustained interest for magneto-optical applications because they combine high transparency with appreciable Verdet constants. However, conventional inorganic magneto-optical glasses typically require melt processing above 1000 °C and often rely on high contents of costly heavy rare-earth components, both of which increase fabrication complexity and cost. In this work, a desolvation strategy was used to prepare a terbium-based hybrid glass at low temperature. The obtained Tb-based glass shows optical transmittance approaching 80%, a Verdet constant of -22 rad/(T·m) at 405 nm, and a glass-transition temperature near 42 °C. Although the relatively low T_g limits thermal durability, the combination of transparency, compositional homogeneity, and field-linear Faraday rotation demonstrates the potential of rare-earth hybrid glasses for compact photonic and sensing applications.

Keywords

Magneto-Optical; Tb-Based Glass; Rare-earth-doped Glasses.

1. Introduction

Magneto-optical glass is attractive because it combines optical transparency with magnetic-field-controlled polarization rotation, enabling Faraday isolators, optical switches, current sensors, and fiber-based magnetic-field detection. In rare-earth-based materials, the most pronounced magneto-optical response generally originates from paramagnetic ions with strong 4f-related transitions, and Tb^{3+} is one of the most effective centers because its electronic structure gives rise to large negative Verdet constants from the visible to the near-infrared region^[1].

Conventional terbium-containing inorganic glasses nevertheless face a persistent trade-off. High-temperature melt processing limits compositional freedom, high rare-earth loading can induce phase separation or crystallization, and enhancing Faraday rotation without sacrificing transmittance remains challenging. Organic or polymer-based terbium systems provide greater coordination flexibility, but they often suffer from poor mechanical robustness, limited thermal resistance, or inadequate optical clarity. Hybrid glasses therefore represent an appealing intermediate platform because, as recent reviews of inorganic-organic photonic hybrids have emphasized, they combine structural adaptability with the design freedom of organic ligands and can help regulate rare-earth coordination and dispersion at high loading^[2].

The present work focuses on a terbium-based hybrid glass derived from terbium nitrate and 4,5-dicyanoimidazole (DCI). DCI is a nitrogen-rich heterocyclic ligand with multiple coordination sites, making it well suited to bind rare-earth ions and promote the formation of a rigid yet noncrystalline metal-ligand network. Recent work has shown that rare-earth nitrate-dicyanoimidazole glasses with

the general formula $\text{RE}(\text{NO}_3)_3(\text{C}_5\text{H}_2\text{N}_4)_2$ can be generated rapidly at low temperature through desolvation while retaining high transparency and functional optical behavior^[3], underscoring the relevance of this structural family.

In the following sections, the experimental observations are reorganized into a formal research narrative and interpreted in light of recent developments in terbium-based magneto-optical materials. Rather than serving as a direct translation of the original text, the discussion connects the measured XRD, DSC, SEM, transmission, magnetic, and Faraday-rotation results with contemporary understanding of hybrid-glass formation, rare-earth coordination, and wavelength-dependent magneto-optical response^[1-3].

2. Experimental Details

The hybrid glass was synthesized by mixing 4,5-dicyanoimidazole (0.236 g, 2 mmol) and $\text{Tb}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ (0.453 g, 1 mmol) in 1 mL of ethanol, heating the mixture to 90 °C until a clear precursor solution was obtained, and then evaporating the solvent in a glass cuvette at 90 °C for 2 h. After natural cooling, a transparent monolithic sample with an approximate thickness of 5 mm was obtained. This route avoids the very high temperatures normally required for oxide-glass melting and instead relies on solvent removal and network formation within a rare-earth coordination framework, consistent with the low-temperature hybrid-glass strategy reported for the $\text{RE}(\text{NO}_3)_3(\text{C}_5\text{H}_2\text{N}_4)_2$ family^[3].

3. Results and Discussion

The XRD pattern in Figure 1 provides direct structural evidence for glass formation. In contrast to the crystalline starting materials DCI and $\text{Tb}(\text{NO}_3)_3$, which exhibit distinct sharp diffraction peaks, the synthesized $\text{Tb}(\text{NO}_3)_3(\text{C}_5\text{H}_2\text{N}_4)_2$ sample displays a broad diffuse halo and lacks obvious Bragg reflections over the measured range. This feature is characteristic of an amorphous solid with only short-range structural order and demonstrates that long-range crystallinity was effectively suppressed during desolvation. Therefore, the XRD result confirms that the synthesized sample is in the glassy state rather than a crystalline coordination compound, in agreement with the structural characteristics reported for related rare-earth-based hybrid glasses^[2,3].

The DSC trace in Figure 2 shows a T_g of approximately 42 °C. This glass-transition temperature is much lower than that of most oxide magneto-optical glasses, reflecting the comparatively flexible bonding topology of a hybrid metal-ligand network. On the one hand, such a low T_g is a practical limitation because thermal deformation or structural relaxation may occur more readily during service. On the other hand, it highlights a defining feature of hybrid glasses: low-energy processing becomes possible when the network is constructed from coordination interactions rather than exclusively from strong oxide bonds^[2].

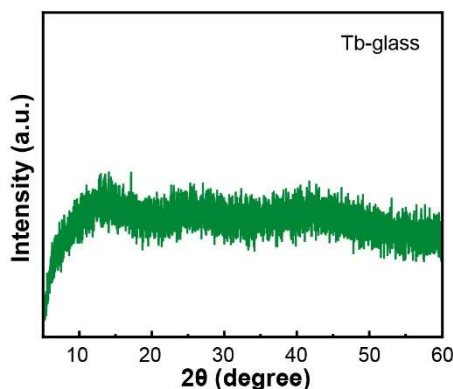


Figure 1. XRD patterns of the $\text{Tb}(\text{NO}_3)_3(\text{C}_5\text{H}_2\text{N}_4)_2$ hybrid glass.

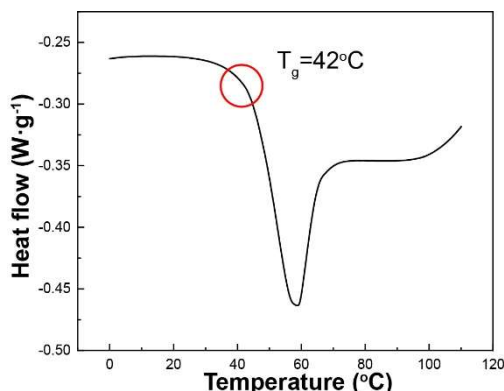


Figure 2. DSC curve of the $\text{Tb}(\text{NO}_3)_3(\text{C}_5\text{H}_2\text{N}_4)_2$ hybrid glass showing T_g near 42 °C.

The SEM image in Figure 3 further supports the claim that the product is a macroscopically uniform glass. The fragment surface appears smooth and free of obvious phase-separated domains at the observed scale, which is encouraging because spatially heterogeneous rare-earth distribution commonly increases scattering and optical loss in highly loaded magneto-optical glasses. As studies of Tb^{3+} -containing magneto-optical glasses have shown^[4], maintaining microstructural uniformity is essential for preserving transmission and device-relevant optical quality. The present SEM result therefore suggests that the hybrid route may provide an effective means of maintaining homogeneity without resorting to extreme melting conditions.

The SEM image in Figure 3 further supports the formation of a macroscopically uniform glass. The fractured surface appears smooth and free of obvious phase-separated domains at the observed scale, which is important because spatially heterogeneous rare-earth distribution commonly increases scattering and optical loss in highly loaded magneto-optical glasses. As previous studies on Tb^{3+} -containing magneto-optical glasses have shown, maintaining microstructural homogeneity is essential for preserving transmission and device-relevant optical quality^[4]. The present SEM result therefore suggests that the hybrid route can effectively maintain compositional uniformity without resorting to extreme melting conditions.

The transmission spectrum in Figure 4 is particularly important from an application perspective. The reported transmittance above 85% across 500-1000 nm indicates that the hybrid glass remains optically viable over a broad visible-near-infrared window. The absorption near 488 nm can be assigned to a characteristic terbium transition, as expected for Tb^{3+} ions with partially filled 4f levels that generate narrow absorption features. Transparency is not merely an auxiliary optical property; for Faraday devices it is a central part of the magneto-optical figure of merit, because a large Verdet constant is valuable only when absorption and scattering remain sufficiently low^[5].

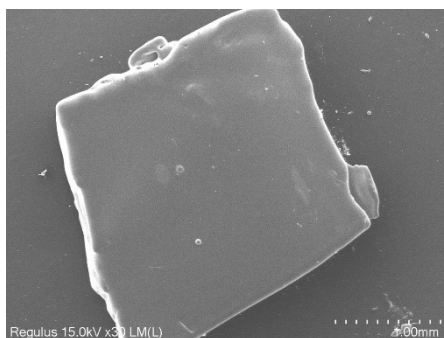


Figure 3. SEM image of the Tb -based hybrid glass fragment.

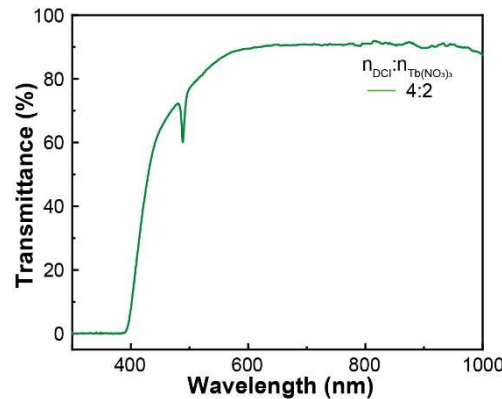


Figure 4. Optical transmittance spectrum of the Tb-based hybrid glass.

The magnetic data in Figure 5 show a linear magnetization-field relationship at room temperature and no detectable hysteresis, clearly identifying the material as paramagnetic rather than ferromagnetic or ferrimagnetic. The source text reports a mass susceptibility of about $5 \times 10^{-5} \text{ emu g}^{-1} \text{ Oe}^{-1}$, which is consistent with the expected behavior of Tb^{3+} -containing glasses. This observation is theoretically significant because the Faraday effect in rare-earth magneto-optical glasses is fundamentally associated with the magnetic susceptibility and electronic transitions of the active ions. In Tb^{3+} , the $4f^8$ configuration gives rise to a large magnetic moment and strong paramagnetic rotation, which is why terbium-rich systems remain benchmark materials for Faraday rotators^[6,8].

The field-dependent Faraday-rotation data in Figure 6 provide direct evidence that the hybrid glass functions as a magneto-optical medium. The nearly linear relationship between rotation angle and magnetic field follows the standard expression $\theta = VBd$, where θ is the rotation angle, V is the Verdet constant, B is the magnetic field, and d is the optical path length. Such linearity is essential for sensing and isolation applications because it implies a predictable conversion between magnetic-field strength and polarization rotation^[1].

The wavelength dependence of the Verdet constant in Figure 7 is equally informative. The absolute value decreases as the wavelength increases from 405 to 577 nm, and the source text indicates that the data can be fitted well by a simplified Van Vleck-Hebb expression. This behavior is consistent with the established theory of paramagnetic Faraday rotation, according to which dispersion is governed by the energetic separation between the probing wavelength and the dominant electronic transitions of the active ion^[7,9-11].

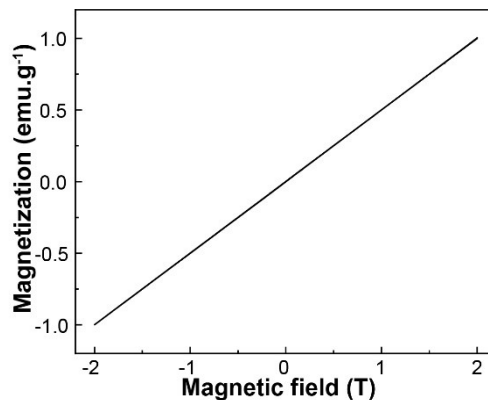


Figure 5. Magnetization as a function of magnetic field at room temperature.

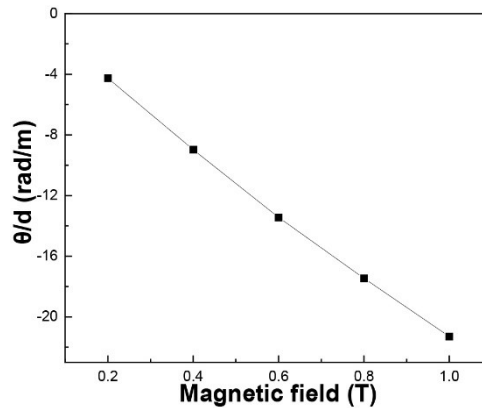


Figure 6. Faraday rotation angle as a function of magnetic field at 405 nm.

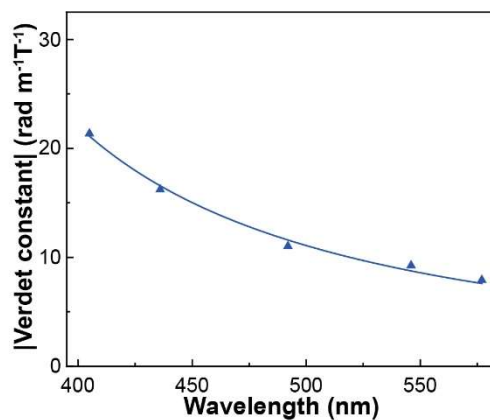


Figure 7. Wavelength dependence of the Verdet constant fitted by a Van Vleck-Hebb-type relation.

A balanced assessment must also recognize the limitations of the present hybrid glass. The T_g of 42 °C is low for many practical photonic environments, indicating that future work should focus on improving thermal robustness by increasing ligand rigidity, introducing secondary network-forming components, or partially densifying the coordination network while preserving transparency. In addition, the present study reports Faraday rotation and Verdet dispersion but does not yet provide a complete figure-of-merit analysis combining Verdet constant with absorption coefficient and thermal conductivity. Such metrics are important for judging competitiveness against established materials for high-power isolators^[5]. Nevertheless, for compact sensors, low-temperature-processable coatings, and niche integrated photonic elements where chemical tunability and ease of fabrication are as important as thermal endurance, this hybrid material family remains highly promising^[3,11,12].

4. Conclusion

In summary, a transparent terbium-based hybrid glass, $Tb(NO_3)_3(C_5H_2N_4)_2$, was successfully prepared by a low-temperature desolvation route. XRD confirmed the amorphous nature of the product, while DSC, SEM, optical, magnetic, and Faraday-rotation measurements collectively demonstrated that the material combines a glassy structure, good homogeneity, high transparency, paramagnetic behavior, and measurable magneto-optical activity. Although the low T_g indicates that thermal stability still requires improvement, the present results show that rare-earth coordination hybrid glasses can provide an effective pathway toward low-cost and low-temperature magneto-optical materials with tunable structure and promising application potential.

Acknowledgments

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