Vol 14 No 8, August 2005
1009-1963/2005/14(08)/1578-03

Chinese Physics

© 2005 Chin. Phys. Soc.
and IOP Publishing Ltd

Femtosecond laser-induced transient grating in CeO_2-doped $75TeO_2$–$20Nb_2O_5$–5ZnO glass*

Zhang Shi-An(张诗按)[a], Sun Zhen-Rong(孙真荣)[a]†, Yang Xi-Hua(杨希华)[a], Wang Zu-Geng(王祖赓)[a], Lin Jian(林 健)[b], and Huang Wen-Hai(黄文昂)[b]

[a] *Key Laboratory of Optical and Magnetic Resonance Spectroscopy, and Department of Physics, East China Normal University, Shanghai 200062, China*

[b] *Department of Materials Science and Engineering, Tongji University, Shanghai 200092, China*

(Received 26 January 2005; revised manuscript received 7 March 2005)

Multiple order self-diffractions by femtosecond laser-induced transient grating in CeO_2 doped $75TeO_2$–$20Nb_2O_5$–5ZnO glass are investigated by pump-probe technique. The glass structure and component are investigated by Raman and visible–NIR absorption spectra. It is showed that there exists Ce^{3+} ion in tellurite glass, and the transient grating is created by the optical Kerr effects and improved by the excited particle grating from the resonant absorption of the $^1S_0 \rightarrow {}^1F_3$ electronic energy transition of Ce^{3+} ion, and the conversion efficiency of the first order diffraction signal reaches about 11%. The results indicate that CeO_2 doped $75TeO_2$–$20Nb_2O_5$–5ZnO glass has potential applications in ultra-fast all-optical switching.

Keywords: tellurite glass, transient grating, CeO_2
PACC: 4270C, 4265M

1. Introduction

Tellurite glass is a very promising material in optical communication systems for its electrical and nonlinear optical properties, such as high nonlinear refractive index, wide infrared transmittance, low melting temperature, low phonon maximum, and higher dielectric constants.[1–5] Recently, tellurite glass doped with some heavy metal oxides or rare earth oxides,[5–9] such as Nb_2O_5, CeO_2 or ZnO, has received great scientific interests because these metal or rare earth oxides can improve the optical and physical properties of tellurite glass. In tellurite glass, there are symmetric or asymmetric units of TeO_4 trigonal bipyramid, TeO_3 trigonal pyramid and an intermediate TeO_{3+1} asymmetric polyhedron.[1] When the additional Nb_2O_5 and ZnO are introduced, Zn^{2+} ion, located outside the network, may induce Nb^{5+} ion into the network, and TeO_4 trigonal bipyramids will transform into TeO_3 trigonal pyramids through an intermediate TeO_{3+1} trigonal polyhedron. Moreover, CeO_2 dopant, as a modifier, can be adulterated in tellurite glass to lower the melting point of tellurite glass without changing the glass network.[7]

In order to satisfy future high-speed optical communication and data process, the picosecond or even femtosecond temporal response and high conversion efficiency of optical switcher are considered. Krumbgel *et al*[10] realized ultra-fast optical switching by using fully phase-matched cascaded second-order nonlinearities with convenient polarization gate geometry in a β-barium borate crystal. Schneider *et al*[11–13] obtained femtosecond switching time in BaF_2 crystal by laser-induced transient grating. In this paper, multiple order self-diffractions from femtosecond laser-induced transient grating are observed in CeO_2 doped $75TeO_2$–$20Nb_2O_5$–5ZnO glass, their conversion efficiency may be improved by the resonant absorption of the $^1S_0 \rightarrow {}^1F_3$ electronic transition of Ce^{3+} ion with laser wavelength (800nm), and the existence of Ce^{3+} ion is confirmed by Raman and visible–NIR absorp-

*Project supported by the Shanghai Priority Academic Discipline, National Nature Science Foundation of China (Grant Nos 102340301 and 10374030), National Key Project for Basic Research (Grant No 1999075200), Key Project sponsored by Shanghai Science and Technology Committee (Grant Nos 036105019 and 03DJ14001) and Twilight Project sponsored by Shanghai Education Committee.

†E-mail: zrsun@phy.ecnu.edu.cn, zrsun@public4.sta.net.cn

tion spectra.

2. Experiment

Appropriate mixture of powders TeO_2 (99.99% aldrich), Nb_2O_5 (99.99% aldrich), ZnO (99.99% aldrich) is melted in gold crucible for 25–30 minutes at 850–950°C. Liquid is quenched to room temperature in steel moulds and annealing treatment is performed at 300–350°C for 2–4 hours. Samples with the composition of $75TeO_2$–$20Nb_2O_5$–5ZnO are instantaneously doped with 0.5% CeO_2. The intact glass is picked out and its surface is polished. The damage threshold of the glass is about 7.7×10^{14} W/cm^2.

The experimental setup for multiple order self-diffractions is shown in Fig.1. A mode-locked Ti (sapphire femtosecond laser pulse (Spectra-Physics Spitfire amplifier)) is used as the excitation source with the pulse duration of about 50fs and the repetition rate of 1kHz. The output laser beam is split into two beams (pump and probe) by a beam-splitter with a ratio of about 1.5:1. The delay between two beams is controlled by a stepper-motor. The two beams have the same polarization (s-polarization) and are crossed in the sample with a small angle. The diffracted light is detected by a silicon pin detector. The integrated intensity of each order diffraction signal is measured as a function of the delay time between the pump and probe beams. The pulse duration is calibrated by sum frequency generation between pump and probe pulses in a 4×4×1 mm BBO crystal.

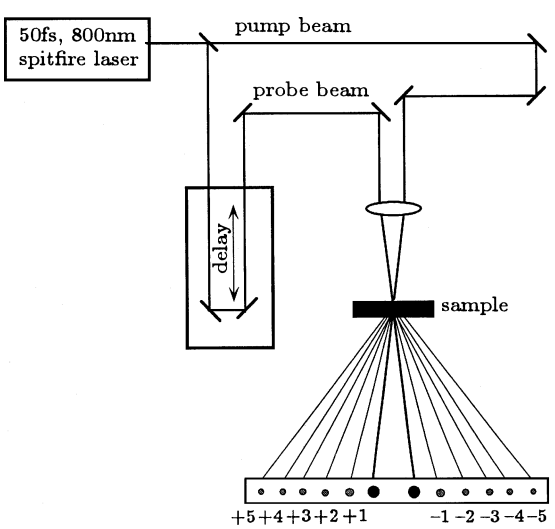


Fig.1. Schematic experimental setup for multiple order self-diffractions by femtosecond laser-induced transient grating.

3. Results and discussion

Ceria (CeO_2) is a promising material for good transparency, good adhesion, mechanical hardness, high refractive index and chemical stability.[14] Generally, it is suggested that CeO_2 may actually be a mixed valence rather a pure 4f compound,[15] involving in two valence states: Ce^{3+} and Ce^{4+}. As shown in Fig.2, the weak Raman peak at about 2400cm^{-1} is assigned to the $^2F_{7/2} \leftrightarrow {}^2F_{5/2}$ electronic transition of Ce^{3+} ion,[16] it is suggested that there exists Ce^{3+} ion in tellurite glass. The Raman bands below 1000cm^{-1} are attributed to phonon mode, there are mainly three wide and asymmetric bands at about 645cm^{-1}, 428cm^{-1} and 227cm^{-1} respectively. The peak at 645cm^{-1} is assigned to the symmetric stretching vibration of Te–^{ax}O bonds in trigonal bipyramids $[TeO_4]^{4-}$ units. The peak at 428cm^{-1} is assigned to the stretching vibrations of the single Te–^{eq}O–^{ax}Te bridges, and the peak at 227cm^{-1} is assigned to the Nb–O vibrations of $[NbO_6]^{7-}$ units.[17] Moreover, the existence of Ce^{3+} ion in CeO_2 doped $75TeO_2$–$20Nb_2O_5$–5ZnO glass is confirmed by the visible–NIR absorption spectrum, as shown in Fig.3. Three absorption peaks are observed at about 585nm, 745nm, and 800nm, which are attributed to the Ce^{4+}–O–Ce^{3+} clusters, the $^2F_{7/2} \rightarrow {}^2F_{5/2}$ electronic transition and the $^1S_0 \rightarrow {}^1F_3$ electronic transition of Ce^{3+} ion, respectively.[18]

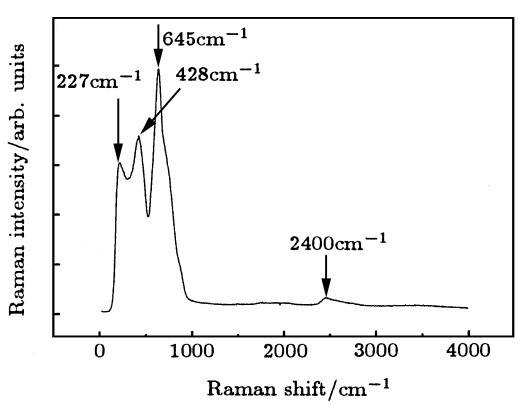


Fig.2. Raman spectrum for CeO_2-doped $75TeO_2$–$20Nb_2O_5$–5ZnO glass.

When two laser pulses with identical wavelength overlap temporally and spatially in a medium, the spatial modulation of their electric fields varies due to constructive and destructive interference. The atoms in the medium experience different electric field intensities with respect to their spatial and temporal position, and this results in a periodic intensity distribution. At high excitation intensity, the refractive index of the material strongly depends on the excitation

intensity due to the optical Kerr effect.[19] The periodic intensity distribution is transformed to the corresponding refractive index modulation, which is known as a transient refractive-index grating.[10,11] The transient grating diffracts the incident pulses, and multiple order diffraction signals can be observed.

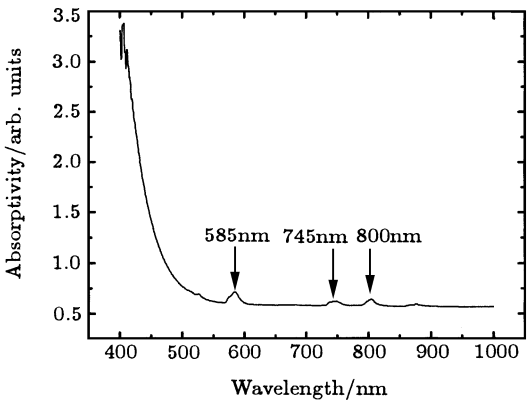


Fig.3. Visible-NIR absorption spectrum for CeO_2-doped $75TeO_2$–$20Nb_2O_5$–5ZnO glass.

Figure 4 shows multiple order diffraction signals as a function of the delay time between pump and probe laser pulses; their response times are about 200fs, more than laser pulse-width (about 50fs). This indicates that multiple order self-diffractions result from a transient grating created by not just optical Kerr effect but also other optical effects with relatively slow temporal response. Because the laser excitation wavelength (800 nm) is resonant with the $^1S_0 \rightarrow {}^1F_3$ electronic energy transition of Ce^{3+} ion, the Ce^{3+} ion in tellurite glass will absorb the input photon and excite to the excited state ($^1F_3$) from the ground state ($^1S_0$), and this results in an excited particle grating formation in the glass. Consequently, the conversion efficiency of multiple order self-diffractions can be improved by the excited particle grating, and the conversion efficiency of the first order self-diffraction signal reaches about 11%. Moreover, the dissipation of absorbed energy will give rise to additional thermal effects, which may result in a thermal grating with a response time of more than picoseconds and a lifetime of more than several nanoseconds. So, the additional thermal effects have no contributions to femtosecond laser-induced transient grating.

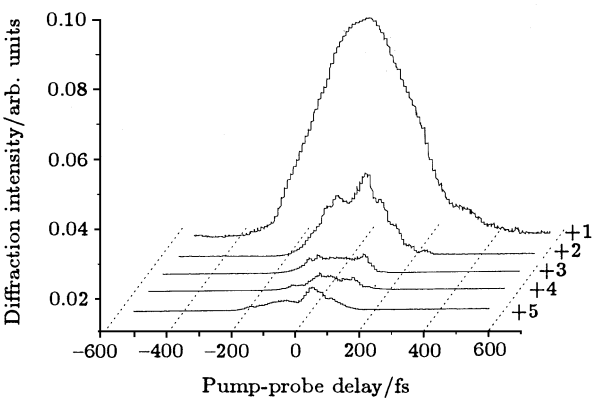


Fig.4. Multiple order self-diffraction signals as a function of the delay time between pump and probe laser pulse. Here, +1, +2, +3, +4 and +5 indicate the orders of multiple order self-diffractions.

4. Conclusion

In conclusion, multiple order self-diffractions by femtosecond laser-induced transient grating in CeO_2 doped $75TeO_2$–$20Nb_2O_5$–5ZnO glass are observed. Multiple order self-diffractions result from the transient grating created by the optical Kerr effects and improved by the excited particle grating. The femtosecond temporal response time and higher conversion efficiency of multiple order self-diffractions indicate that CeO_2 doped $75TeO_2$–$20Nb_2O_5$–5ZnO glass has potential applications in ultra-fast all-optical switching.

References

[1] Kowada Y, Morimoto K, Adachi H, Tatsumisago M and Minami T 1996 *J. Non-Cryst. Solids* **196** 204
[2] Weng L and Hodgson S N B 2002 *Opt. Mater.* **19** 313
[3] Nasu H, Matsushita O, Kamiya K, Kobayashi H and Kubodera K 1990 *J. Non-Cryst. Solids* **124** 275
[4] Vijaya Prakash G, Narayana Rao D and Bhatnagar A K 2001 *Solid State Commun.* **119** 39
[5] Berthereau A, Fargin E, Villesuzanne A, Olazcuaga R, Le Flem G and Ducasse L 1996 *J. Solid State Chem.* **126** 143
[6] EI-Mallawany R 1998 Mater. *Chem. Phys.* **53** 93
[7] EI-Mallawany R, EI-Sayed A H and EI-Gawad M M H A 1995 *Mater. Chem. Phys.* **41** 87
[8] Zhang S A *et al* 2004 *Chin. Phys.* **13** 1287
[9] Ma H P *et al* 2004 *Acta Phys. Sin.* **53** 1378 (in Chinese)
[10] Krumbgel M A *et al* 1997 *Opt. Lett.* **22** 245
[11] Schneider T *et al* 1999 *Appl. Phys.* B **68** 749
[12] Reif J *et al* 2002 *Appl. Phys.* B **74** 745
[13] Schmid R P *et al* 2002 *Appl. Phys.* B **74** 205
[14] Kanakaraju S *et al* 1997 *Thin Solid Films* **305** 191
[15] Flynn C P and Stoneham A M 1970 *Phys. Rev.* B **1** 3966
[16] Otake T, Yugami H, Naito H, Kawamura K, Kawada T and Mizusaki J 2000 *Solid State Ionics* **135** 663
[17] Sidebottom D L, Hruschka M A, Potter B G and Brow R K 1997 *Appl. Phys. Lett.* **71** 1963
[18] Zhang S A *et al* 2004 *Opt. Commun.* **241** 481
[19] Le Blanc S P *et al* 1991 *Opt. Lett.* **16** 1508