Photon-Induced Borate Groups Transformation by Femtosecond Laser

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Abstract In this paper, we put emphasis on the analysis the mechanism of the photon-induced frequency conversion β-BaB2O4 crystal inside a borate glass using femtosecond laser. Because of the nature of femtosecond laser’s ultra-short pulse duration and high-energy density, in essence the laser-glass interaction mechanism is changed. Based on multiphoton ionization, collisional ionization and the network depolymerization in the borate glass, production of the plasma drives the microstructure rearrangement near the laser beam focusing area. From the structure of glass and crystal analysis, we conclude that the complicated borate groups containing BO3 and BO4 units inside the glass are converted into (B306)3 anion rings.

Key words femtosecond laser, multiphoton absorption, collisional ionization, network depolymerization.

1 Introduction

Since the 90’s, the femtosecond laser techniques have been used to study various ultra-process within materials, because of its high time-resolution. In chemical reactions, chemical bond breaking or bond formation is on the scale of femtosecond (10-15 second)[1]. With femtosecond laser it is now possible to record snapshots of chemical reaction with sub-angstrom resolution.

In general, it is difficult to produce an interaction effect between glass and light by a single photon process[2] when the excitation wavelength differs from the wavelength of absorption bands in the glass. However, researchers have reported various types of structural changes produced in the many types of glass by femtosecond laser irradiation during recent years, for example, photon-induced damage, photon-induced color-center generation and photon-induced refractive index change, etc. The photon-induced β-BaB2O4 crystal formation was reported in Ref.[3], Which is a novel method growing crystal. The growth of the three-dimensional frequency conversion crystals in bulk glasses opens new possibilities in the field of compact short wavelength coherent light source. On the other hand, this technique is expected to provide new compact waveguides as nonlinear-optic frequency conversion devices. In this paper, we study the Raman scattering data obtained from a borated glass illuminatated with a femtosecond laser and the X-ray experiment is Ref.[3], in order to explore the β-BaB2O4 crystal growth mechanism[3].

2 Structure of Borate Glass and the β-BaB2O4 Crystal

Metastable borate glass belongs to a kind of non-crystalline solid. The structure and physical properties of borate glass have been studied extensively. Borate glass in the binary system with an alkali oxide exhibit some well-known and much discussed anomalies, generally referred to as ‘the boron oxide anomaly’. The anomalies in the binary alkali borate have received a structural explanation by Warren. When alkali oxide adds to boron oxide, boron is transformed from the threefold-coordinated state into the fourfold-coordinated state with the formation of BO4 tetrahedra. Cations do not enter the network and are located...
near two BO₄ tetrahedras compensating for their negative charge. The BO₄ tetrahedra remains isolated from each other by the BO₃ triangles. A BO₄ unit can be incorporated in a structural group in various ways. Various structural groups consisting of BO₃ and BO₄ units are probably present in a mixed system, and the glass is built up by various groups such as the triborate groups, the di-triborate groups, the diborate groups and tetraborate groups as shown in Fig. 1.

The fl-BaB₂O₄ crystal is an ionic-type molecular crystal, built up by Ba⁺² cations and (B₂O₆)⁻³ rings alternately, and the structure can be considered as a layer step-type lattice.

3 Results of the Experiments

In the past years, we have studied the Raman spectra of the β-BaB₂O₄ crystal under high temperature. The spectra under different temperature is shown Fig. 2. The wave number 630 cm⁻¹ of Raman peak assigned to the (B₂O₆)⁻³ ring is a finger print of the β-BaB₂O₄ crystal’s Raman spectra.

Recently, we carried out experiments on Raman spectrum of the glass smaple as described in Ref. [3], and have observed Raman spectra on the focal point of the femtosecond laser beam irradiation in borate glass as shown in Fig. 3. The presence of the sharp peak at 630 cm⁻¹ illustrates crystallization must have taken place in focused area. The peaks above 230 cm⁻¹ in Fig. 3(irradiated) are attributed to the translation and vibration of the (B₂O₆)⁻³ ring, in perfect agreement with Raman spectra of the β-BaB₂O₄ crystal at room temperature as shown in Fig. 2. Based on our results and the measurement of X-ray patterns in Ref. [3], we conclude that the complicated borate groups are converted into the (B₂O₆)⁻³ ring in the focused area.

4 Mechanism of the BBO Crystal Growth Inside Glass

The structural rearrangement and damage inside glass in confined to a small region around the peak of