Growth and characteristics of novel optical single crystals

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Recently, optical technology progress in a wide range of applications, and at the same time, still demands the further development. One of the key issues is to present new optical sources in UV/VUV wavelength region. Another one is to increase laser power. Since conventional crystal materials face some of the limitations, these issues require new optical single crystals. In this presentation, ferroelectric fluoride, β-Ga_2O_3 and magneto-optical garnet single crystals, which have advantageous characteristics toward the above demands, will be introduced as representative recent research subjects of our group.

The use of ferroelectric fluoride single crystals for SHG at UV/VUV by the quasi phase-matching (QPM) technique, which is non-critical at any wavelength, is proposed. $BaMgF_4$ (BMF) single crystals up to 2 inch in diameter were grown by the Bridgman and Czochralski techniques. These are non-centrosymmetric (space group $Cmc2_1$) and exhibited a wide range of transparency from VUV to IR wavelength region. Well-saturated hysteresis loops with coercive fields as small as 4 kV/cm were shown. BMF *c*-cut plates were periodically poled (PP) with different periods for the fabrication of QPM devices. With these we could demonstrate for the first time laser emission from a PP fluoride single crystal. SHG was obtained in the visible and UV using Nd:YAG and Ti:sapphire lasers as sources.

β-Ga_2O_3 belongs to the monoclinic system (space group C2/m) and exhibits the largest band gap (E_g = 4.8 eV) among the transparent conductive oxides (TCOs). Growth of 1 and 2 inch size β-Ga_2O_3 single crystals by the FZ and EFG techniques, respectively, and subsequent cutting and fine polishing of wafers were achieved in spite of its diverse growth and processing difficulties. They are highly transparent from the visible wavelength region to the absorption edge, while the free carrier absorption in the infrared is indicative of its conductive character. Epitaxial growth of *c*-plane wurtzite InGaN-MQW on *a*-plane β-Ga_2O_3 was realized by the MOCVD technique. Vertical structured blue LEDs on β-Ga_2O_3 with different packaging styles were demonstrated.

$Tb_3(Sc_{1-x}Lu_x)_2Al_3O_{12}$ single crystals have been designed and grown for magneto-optical isolator applications, especially for high-power laser machinery. $Tb_3Al_5O_{12}$ exhibits the best magneto-optical features; however its incongruent melting nature has lead to the industrial use of $Tb_3Ga_5O_{12}$. By the isovalent substitution of Al^{3+} by Sc^{3+} and Lu^{3+} in the octahedral site of the garnet structure, it was possible to improve the growth characteristics while preserving the superior magneto-optical properties. $Tb_3(Sc_{1-x}Lu_x)_2Al_3O_{12}$ crystals showed a higher visible transparency and a larger Faraday rotation than $Tb_3Ga_5O_{12}$ crystals.

$Tb_3(Sc_{1-x}Lu_x)_2Al_3O_{12}$ is therefore very promising material in particular for new magneto-optical isolator applications in the visible-near IR wavelength region.

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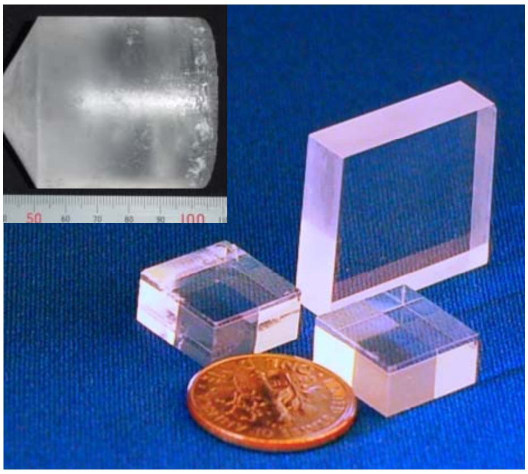

Fig.1: Ferroelectric 2 inch $BaMgF_4$ single crystal grown by the Bridgman tech.

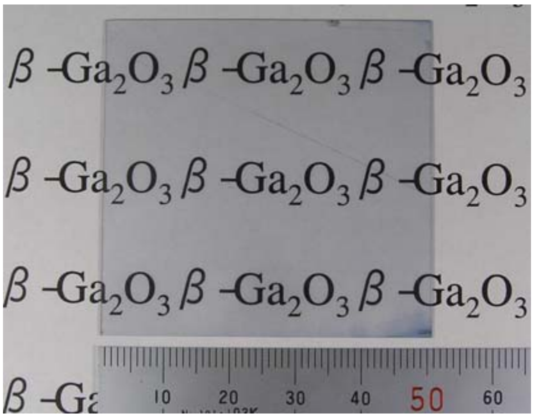

Fig.2: Both side polished 2 inch β-Ga_2O_3 single crystal grown by the EFG tech.

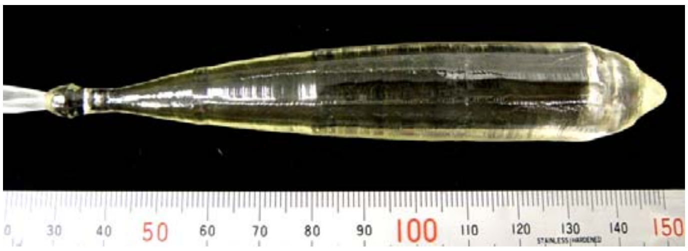

Fig.3: Magneto-optical $Tb_3(Sc_{1-x}Lu_x)_2Al_3O_{12}$ single crystal grown by the Czochralski tech.