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Mazer's theory application in $Bi_4Ge_3O_{12}$:V

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Abstract*: The recent development of coherent light amplifiers and oscillators, now generally referred to as optical masers "or lasers," has made feasible a host of new uses and applications of electromagnetic wave energy in the optical portion of the spectrum. Furthermore, the high degree of monochromaticity obtainable from an optical maser makes it a useful tool for spectroscopic investigations as well as for stimulating various types of chemical and physical reactions. The effect of vanadium doping transforms $Bi_4Ge_3O_{12}$ single crystals into optical maser. This result can be observed after thermoluminescence at 556 nm.*

Keywords*: optical maser, vanadium doping, Shrödinger's time-dependent equation.*

Introduction

Bismuth Germanate crystals, known also as Eulytine, are colourless, transparent (from 300 to 6000 nm) and insoluble in water, with mechanical, chemical, thermal and radiation stability. They have found a wide range of applications such as scintillator materials for x-ray, γ-ray and particle detectors due to their room-temperature luminescence [1]; a solid state laser host matrix of rare-earth ions [2]; in opto-electronic devices as voltage and electric field sensors [3], as well as media for holographic data storage [4]. BGO crystals are isotropic and non-gyrotropic. They crystallize in *43m* point group symmetry with a cubic structure, and have four chemical formula units in each cell. Each Ge^{4+} ion is coordinated by four oxygen ions arranged in a GeO_4 tetrahedron, and each Bi^{3+} ion is coordinated by six oxygen ions, forming a BiO_3 octahedron [5]. BGO has a large energy gap (4.14 eV), which appears to be a suitable matrix for extrinsic impurities such as transition metals or rare-earth elements. Furthermore, use of an appropriate dopant is an easy way to improve the photosensitivity and optimize the physical properties of BGO crystals for future practical applications. The aim of this work is connected with the application of the quantum and semiclasical radiation theories to the $Bi_4Ge_3O_{12}$:V as optical maser.

Materials and Methods

BGO single crystals doped with vanadium are grown by Czochralski technique [6]. Some stohiometric Bi_2O_3:GeO_2 powders are mixed in a molar proportion 2:3. The purity of Bi_2O_3 and GeO_2 is 99.999% in the mixture. The growth conditions have been established by the automatic diameter-weight control. The vanadium is introduced to the melt solution during the crystal growth in the form of V_2O_5 oxide. The concentration of doping element is V – 7×10^{18} cm^{-3} [7].

Results and Discussion

The optical structure which consists of strongly overlapped maxima in the absorption spectrum of the illuminated crystal (600-1000 nm). This structure is conditioned by the presence of V^{4+} in the region of

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transparency of the crystal. It determines the appearance of the photochromic effect dues only of the vanadium ions (fig. 1). The optical structure in the region of transparency disappears completely by heating the crystal in air at temperatures up to 400^0C (fig. 1). The crystal passes in the annealed state. The illuminated crystal after the exposure can spontaneously recover its optical transparency about to values, which is shown prior to irradiation. The recovery process is highly dependent on the temperature. The thermoluminescence emission of the illuminated crystal is measured for 13 lengths of light in the spectral region 320-670nm. For this purpose, narrow band interference filters are used. The illuminated crystal is heated to 400^0C. The number of emitted quanta registers with photon counter. The wide band of thermoluminescence emission is observed with a maximum at 556nm [8]. The pump light for BGO: V has the energy E_0 = 540 pHz or the wavelength λ = 556 nm (fig. 2). The comparison between quantum and semiclassical radiation theories are applied in a study of amplitude and frequency stability in a molecular beam maser. The Shrödinger's time-dependent equation is solved for a perturbed molecule by a classically described field.

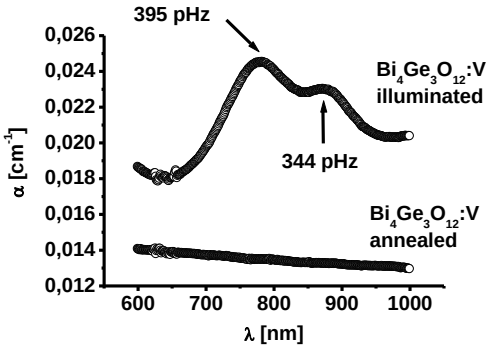

Figure 1. The absorption spectra of $Bi_4Ge_3O_{12}$:V (illuminated) and $Bi_4Ge_3O_{12}$:V (annealed) in the spectral region 600-1000 nm.

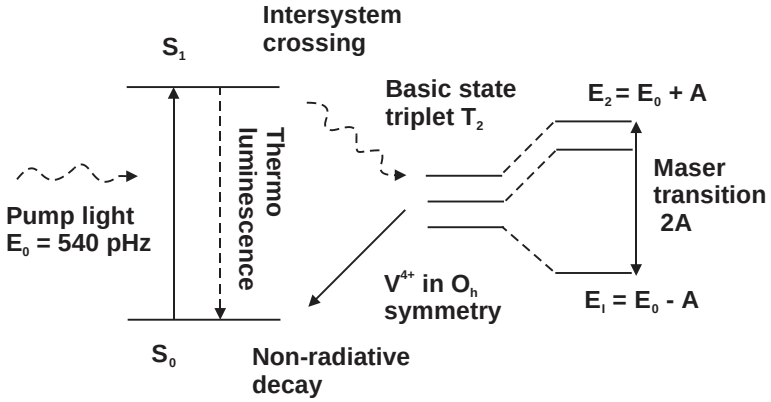

Figure 2. The vanadium doped eulitine as coherent light amplifier.

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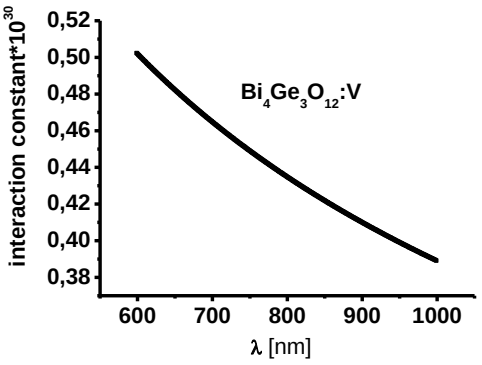

Figure 3. The spectral dependence of the interaction constant.

The expansion of electromagnetic fields in terms of resonant modes of the particular cavity is under consideration. The cavity normal mode functions are used as they have been defined by Slater [9]. The cylinder cavity volume is V which is bounded by a closed surface S. The ions V^{4+} travel in the maser along z axis of the cylinder. The eigenfunction $E_{az} = \frac{1}{J_1\sqrt{V}} = 4.344 * 10^{15}$, where $J_1 = \frac{\Omega\mu}{2V}$ [10].

The lossless cavity has only a single resonant mode near the natural line frequency of the vanadium ion and a uniform field along the path of these ions. The interaction Hamiltonian between V^{4+} ion and field is taken of the form H_{int} = -μE, where μ is the electric dipole moment of this ion. $\alpha = \frac{\mu}{J_1}\sqrt{\frac{2\pi\omega}{\hbar V}} = \frac{12{,}2949*10^{27}}{\sqrt{\lambda}}$ is the interaction constant (fig. 3). If we consider the case of two coupled pendulums, the energy of the vanadium ion W is a constant.

$$\nu^2 = \frac{\omega^2+\Omega^2}{2} \pm \frac{1}{2}\sqrt{\left(\omega^2 - \Omega^2\right)^2 - 4K^2SW},$$

where $K = 2\mu/\hbar = 0.8115 * 10^6$ and $S = 4\pi\omega^2/J_1^2V$. If W>0 and the cavity is tuned so closely to the natural line frequency that $\left|\omega^2 - \Omega^2\right| < \sqrt{4K^2SW}$, the square root in the equation of ν^2 becomes imaginary; one of the normal modes grows exponentially, the other decays. Now an oscillation of growing amplitude represents energy being transferred from vanadium ion to field and therefore we see that the semiclassical theory does lead to a prediction of spontaneous emission. Since W is just the energy of the ion V^{4+}, we see that the condition of unstable growing oscillation is just that the vanadium's wave function contains more of the upper state than the lower, $|b|^2 > |a|^2$ ($b = \frac{4\omega^2}{SK^2\hbar\omega} = \frac{1}{2\alpha^2}$, $a = \frac{C}{S\hbar\omega}$). The constant C can be determined by the next equation: $2\omega^2\left(\dot{W}\right)^2 - SK^2W^3 + \frac{K^2CW^2}{2} + SK^2\left(\frac{\hbar\Omega}{2}\right)^2 W = \frac{K^2C}{2}\left(\frac{\hbar\Omega}{2}\right)^2$. Suppose that the cavity is tuned exactly to the natural line frequency, ω = Ω. Then the equation of ν^2 reduces to $\nu^2 = \omega^2 \pm i\sqrt{K^2SW}$ or to an extremely good approximation, $\nu = \omega \pm \frac{i\sqrt{K^2SW}}{2\omega}$. If we start with the vanadium ion nearly in the upper state then W = ħΩ/2 and the amplitude of the field varies like $exp\left(\frac{\sqrt{K^2SW}}{2\omega}t\right)e^{i\omega t} = exp\alpha t e^{i\omega t}$. This formula describes spontaneous emission according to quantum electrodynamics. Whenever the vanadium ion has a dipole moment different from zero, the fields set up by this dipole react back on the ion and change its state in such a way that energy is delivered to the field, as long as W > 0. These linear relations do not hold indefinitely, of course. From the conservation law $\dot{M}^2 + \Omega^2M^2 + K^2W^2 = const = \left(\frac{K\hbar\Omega}{2}\right)^2$ (M is the dipole moment of the vanadium ion) it is clear that when the amplitude of the M oscillation increases, the magnitude of W must decrease, and this will eventually put a stop to the emission process.

Conclusions

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The frequency ν of the oscilation , the energy of the vanadium ion W and the dipole moment M are calculated during the emission process for $Bi_4Ge_3O_{12}$:V. These characteristics are so important when this crystal have to be used as optical maser in the practice. Our investigation is connected with the presentation of the theoretical model of the maser transition in this crystal sample.

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References

[1] Okajima K., Takami K., Ueda K., Kawaguchi F., *Rev. Sci. Instruments* 53, **1982**, 1285.
[2] Kaminskii A., Sarkisov S., Denisenko G., Ryabchenkov V., Lomonov V., Perlin Yu., Blaza M., Shultze D., Hermoneit B., Reiche P., *Phys. Status Solidi A* 85, **1984**, 553.
[3] Kamada O., Kakishita K., *Jap. J. Appl. Phys.* 32, **1993**, 4288.
[4] Montemezzani G., Pfandler St., Gunter P., *JOSA B* 9, **1992**, 1110.
[5] Martin A., Bravo D., Dieguez E., Lopez F. J., *Phys. Rev. B* 54, **1996**, 12915.
[6] Marinova V., Lin S.H., Hsieh Mei-Li, Gospodinov M.M., Hsu K.Y., *Optical Memory and Neural Network* 11, **2002**.
[7] Petrova D., V. Marinova, P. Petkova, Liu R.C., Lin S.H., Hsu K.Y., *JOAM-Symposia* 3, 308–310, **2009**.
[8] Dimov T., Iliev I., Petkova P., *The qualitative model of the photochromic effect kinetics of $Bi_4Ge_3O_{12}$:V – in press*
[9] Slater J.C., *Microwave Electronics* ch. 4, D. van Nostrand Co., Inc., New York, **1950**.
[10] Dowling J.P., *Foundations of Physics* 23 (6), **1993**.

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