FOREWORD.

F1. During the last two decades (1979-1999) the so called Softening Complex for the Gamma-Lasing is growing. This Complex is developing slowly but permanently and steadily as a certain tree. The Main Present Branch of that Tree called as SPTEN (Soft Prompt Transplantation of the Excited Nuclei) is outlined in the Addendum.

F2. The SPTEN's apparition is not sudden. It has many precursors. Many ideas, analytical and critical works on γ-laser items and on the adjacent fields of science and technique facilitated the way to the SPTEN. The Author is very appreciative to its Authors as like as to his Old Good Teachers. Especially to those who spend the time for the discussions. So the SPTEN organically joints great manifold of the scientific and trial ideas and results.

F3. SPTEN joints differ ideas, methods and theories on base of One Single Program. The Main Principle of that Program is a Feed Back Conception about mutual links in a total complex of beneficial and adverse processes in Real γ-Laser. In result the merits of all adopted ideas enhance each other. But all adverse processes and hindrances resident in that ideas are suppressed. Indeed SPTEN divides, isolates and in a such manner suppresses all its hindrances but it joints the beneficial sides of adopted ideas with its mutual enhance.

F4. SPTEN-γ-Laser can do without use of Hyper Fine Structure in the site of the Active Medium.

F5. SPTEN-γ-Laser can do without use of any External Fields (Laser, Radio-Frequency, Static, etc.) in the site of the Active Medium for the line narrowing.

F6. SPTEN-γ-Laser can do without use of any fields in the site of the Active Medium for the creation of the inverse population.

F7. SPTEN-γ-Laser can do without use of any fields in the site of the Active Medium for the creation of so called Amplification Without Inversion.
Gamma-Ray Solid Laser: Amplification without Inversion and Microplasma of Active Medium.

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This report results from a contract tasking Russian Academy of Sciences as follows: The contractor will identify and evaluate nuclei that may be used in the straight experimental demonstration of gamma-laser oscillations as described in his proposal.

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F8. SPTEN creates the most favorable conditions for the cooling of Active Medium at the period of both the pumping and the γ-lasing.

F9. Active Medium at SPTEN-pumping is an Unusual Medium. It is a Hybrid of Cold Solid Host-Lattice with the Hot Non-Equilibrium Light Micro-Plasma: T_{host} < 30 K, T_{micro-plasma} > 30 000 K.

F10. It leads to the natural transforming of the inhomogeneous wide-band Moessbauer spectrum into only one distinct narrow line.

F11. Hence it is no ever branching that is very beneficial for the γ-lasing.

F12. The main input part of the SPTEN is the so called Multi Beam Emitter (MBE), which creates well oriented and powerful Multi Beam of atoms or ions with the Excited Nuclei. The Multi Beam contains a big amount ~ 10^4 of ordinary beams (so called microbeams), which are mutually exactly paralleled. The MBE can be applied distinctly without a γ-laser. And it is very probable that MBE would be created long before than its «parent», i.e. the γ-laser.

F13. The main merit of SPTEN is its possibility to be very variable, to do with many nuclei and hosts, to do with many sources, to do as a hybrid with many other γ-laser types, to simulate other γ-laser types before its realization.

F14. SPTEN holds many other merits and properties. Some its part is regarded in the Present Work and in its Addendum.

F15. The SPTEN needs be widely declared and discussed. Because even if only a small part of all above is a truth then it leads to the very serious changing in the Present Status of Gamma-Laser Problem, viz.,
- The rise of the SPTEN-direction would then mean that:
  - 1. The Gamma-Laser Creation HAS BEEN TRANSFERRED FROM the Category of the Principally Non-Resolved Problems INTO the Category of the Feasible Indeed but Very Complex Technology Tasks.
  - 2. The many-decades Stage Devoted to the Negotiation of the Principal Difficulties’ Complex in Gamma-Lasing Creation IS FINISHED.
  - 3. The next Stage of the Scientific-Engineering Elaboration and the Technology Preparation for the Indeed Realized Direct Trials with the Immediate Detecting of the Gamma-Lasing IS OPEN.

F15. Russian. Необходимо широкое обнародование и обсуждение SPTEN. Потому что, если даже только небольшая часть высказанного подтвердится,
то это приведет к серьезным изменениям в нынешнем состоянии дел в проблеме гамма-лазера, а именно,
- Появление SPTEN тогда бы означало, что:
  - 1. Создание Гамма-Лазера ПЕРЕШЛО ИЗ Категории Принципиально Нерешенных Проблем В Категорию Осуществимых На Деле, но Очень Сложных Технологических Задач.
  - 2. Длительный этап идет по пути Этап Преодоления Комплекс Принципиальных Трудностей ЗАВЕРШЕН.
  - 3. ОТКРЫВАЕТСЯ Этап Научно-Технической Разработки и Технологической Подготовки На Деле Реализуемых Прямых Экспериментов с Непосредственным Детектированием Гамма-Лазерной Генерации.

F16. But a pair of Big «No» exists.

The first «No» is that MBE and SPTEN are yet created only at the paper. And it needs very long period for its realization indeed. It is the truth. And hence the theorists have some years in order to check each element of MBE and SPTEN by different means before the experiments. One of such checking is the Present Work of the Author devoted to the use of Photonuclear reactions in the SPTEN. The second «No» is that these methods are very complex already yet now. And these methods will become else more complex. Because its will be covered by some layers of the specialty of the next order.

It is the well known south that each new answer leads to the new envelope of the sub-problems of the next generation. But it is not a lack of the SPTEN. Vice versa it is a big merit of the SPTEN. It is the apparent argument of that the SPTEN method is growing, developing and conquering all new difficult questions on its way to the real experiment. Already yet more than twenty years the SPTEN stands the all-round checking by the time lapse.

F16. Russian. Однако, существуют два Большых «Но».

Во-первых, MBE и SPTEN созданы пока только на бумаге. И до их реализации в эксперименте пока очень далеко. И это действительно так. Значит, у теоретиков есть еще несколько лет, чтобы основательно проверить каждый элемент в SPTEN, прежде чем начнутся эксперименты. Одной из таких проверок является Настоящая Работа Автора, посвященная использованию Фотондерных реакций в SPTEN.
Bo-vtorых, эти методы очень сложны уже сейчас. И эти методы станут еще сложнее. Потому что они обрастают несколькими слоями подробностей, соответствующих преодолению трудностей следующих порядков. Связано это с известной истиной о том, что каждый ответ при решении сложной проблемы порождает множество новых вопросов, т.е., каждый комплекс ответов порождает новый слой проблем следующего порядка. Но это не недостаток, а достоинство модели SPTEN, т.к. это есть бесспорное доказательство того, что она растет, развиваясь, преодолевая все новые и новые вопросы и трудности на своем пути. Уже более двадцати лет SPTEN выдерживает всестороннюю проверку временем.

F17. The Present Work is based on a row of fundamental works. It is based particularly on two Invited Lectures:
and
II. The Invited Lecture at the International Conference on the Fundamental Problems of Laser Optics’98 (LO’98), St. Petersburg: S.V.Karyagin, «Gamma-Ray Solid Laser: Amplification Without Inversion and Microplasma of Active Medium. Some Results in Substantiation for a Feasible y-Lasing Experiment» referred in Present Work as [35].

This Second Lecture contains the main results of the first one. Besides the Second Lecture
- introduces the very perspective novel candidate 58Co;
- constructively analyses the SPTEN-class;
- constructively analyses the OTHER CLASSES at the comparison with the SPTEN;
- revises and modernizes the induced and super-radiant emission theories.

On this base just exactly the Second Lecture is adopted as the Addendum for the Present Work. This Addendum is differ from the simple copy of the Ref.[35] because in the Addendum
- some errata (especially in the formulas) are corrected;
- some vague phrases are changed or are detailed.


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Gamma-ray solid laser: amplification without inversion and microplasma of active medium
Some results in substantiation for a feasible γ-lasing experiment
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ABSTRACT
Some results in substantiating for a feasible γ-lasing experiment are considered. Self microplasma (SM) existence in active medium (AM) is set up. SM-density at other pumping types is more by several orders than one at soft prompt transplantation of excited nuclei (SPTEN). Hence schemes of amplification without inversion (AWI) are broken down by the SM. Types of AWI and γ-lasers steady against SM are revealed. “Width-path effects” (L-effects) on Moesbauer spectrum and on a γ-lasing are predicted. Radiation-heat regimes and γ-lasing conditions (induced, super-radiant) are studied. Difficulties of gas-AM (in beams) are analyzed. New candidate 58Co (28.1 keV, 1.51 10^7 s) is suggested. Efficiency of SPTEN and industrial laser isotope separation can be drastically increased on base of proposed so called “atomic (molecular) multi-beam emitter”.

Keywords: gamma-ray solid laser, cooling of active medium, isomeric transitions, quantum nucleonics, selective resonant pumping, amplification without inversion, Bormann effect, collapse of Moesbauer spectrum by motion of charged carriers.
1. INTRODUCTION

From early works (1961, Rivlin; 1963, Baldwin et al.) up to nowadays a big world experience in γ-laser (GL) is stored. A crisis in GL-problem was happened just before 1980-th: no real nuclei-candidates, "heat death" of GL, etc. That crisis stimulated creation of a hybrid model\(^1\) on joint of a row GL-directions adopted with all world GL-experience account. In works\(^1\) and here a feasible model of gamma-ray solid laser on short-lived isomers using a method of so called soft prompt transmutation of excited nuclei (SPTEN)\(^1\) is developed. Active medium (AM) is creating during the short time of isomer-implantation with kinetic energy of ions less than 0.5 keV. So the AM is created with list heating and negligible substrate destruction. Theory and computer simulation show\(^1\) that just after such pumping a big density of excited lasing-active nuclei (ELAN) \(n > 10^{21} \text{cm}^{-3}\) at a high relative population \(n_{\text{rel}} > 0.9\) and more than sufficient amount of ELAN \(N_{\text{el}} = n_{\text{rel}}V_{\text{am}} > 10^{13}\) in active medium (AM) of volume \(V_{\text{am}} \sim 10^{-2} \text{cm}^3\) could be reached. At SPTEN an existence of resolved hyperfine structure (HFS) for working transition is not necessary. Moreover, a collapse of HFS (see 1.6) is beneficial for γ-lasing\(^1\)–\(^3\).

1.1 Candidates for gamma-ray solid laser

This model\(^1\) is able to use a plenty of different working nuclei-candidates arisen in many reactions, including photo-processes, non-elastic (e.g., Coulomb) scattering of particles on parent nuclei, non-elastic (e.g., Coulomb) scattering of parent nuclei passed through crystal, particle-exchange, etc. Widely known nuclide \(^{106}\)Ta is only the most studied "satisfactory" candidate. However even such candidate answers all in situ and ex situ demands of a real experiment\(^1\)–\(^3\).

Here a new candidate \(^{59}\)Co is suggested. In this case a working transition (WT) has energy \(E_\gamma = 28.1 \text{keV}\); wavelength \(\lambda = 4.41 \times 10^{-8}\) cm. Time-life (decaying by factor \(e^{-1} = 0.368\)) \(\tau_\gamma = 1.51 \times 10^{-8}\) s. Internal conversion coefficient \(\alpha = 1.5\). In diamond matrix (diamond of IIa-type) Debye temperature \(T_D = 1860 \text{K}\). Case of \(^{59}\)Co in diamond is marked as \(^{59}\)Co/Di. At temperatures \(T < T_D\) a factor of recoilless emission \(f = 0.86\). Both working levels (WL), upper "+" and lower "−", are excited. Branching ratio of WT is \(w = 0.999\). Adopted here time-ratio \(\tau_\gamma/\tau_\gamma = 1.1\). A total width of WT \(\Gamma_{\text{tot}} = \Gamma_{\text{am}}\) is "effected by distance", see 2.1. Nuclear moments of WL are \(J = 4^+\) and \(J = 5^+\). The time-life of lower WL is \(\tau_\gamma = 4.78 \times 10^{-8}\) s. The time-life of ground state is \(\tau_\gamma = 8.83 \times 10^{-6}\) s. The ratio of statistical weights \(g = (2j+1)/(2J+1) = 9/11 = 0.818\). Isolated resonant cross-section (at ratio \(\tau_\gamma/\tau_\gamma = 1\), in a frequency-maximum, without HFS) is \(\sigma_\gamma = 1.1 \times 10^{-24} \text{cm}^2\). Conventional cross section of resonant self-absorption \(\sigma_{\text{aa}} = g \times 8.75 \times 10^{-24} \text{cm}^2\). Cross-section of self non-resonant losses on Co-atoms \(\sigma = 1.2 \times 10^{-25} \text{cm}^2\). Cross-section of non-resonant losses on C-atoms of diamond \(\sigma = 5.63 \times 10^{-23} \text{cm}^2\). Exitated laser-active nuclei (ELAN) \(^{59}\)Co\(^*\) could be created (as recoiled nuclei) in so called "converters"\(^3\), e.g., at reactions \(^{59}\)Ni(n,p)\(^{59}\)Co\(^*\) or \(^{59}\)Co(n,2n)\(^{59}\)Co\(^*\) with cross-section \(\sigma = (0.5 - 0.8) \times 10^{-25} \text{cm}^2\). Even at such small value of \(\sigma\) the SPTEN can fit \(N_{\text{max}} \sim 10^{13} - 10^{14}\) of ELAN at AM site\(^3\). There are many types of AM-body forms\(^5\). The simplest one has a quadrature in its cross-section with a side d, and a length L. AM has dispersed micro-profile (see 1.4) with external (visible) volume \(d \times d \times L\). Let concentration of working nuclei (WN) is \(n = 9 \times 10^{25} \text{cm}^3\), its total number \(N_{\text{n}} = 2 \times 10^{11} N_{\text{max}}\) and content of ELAN at the initial moment is 0.9. Then a length of AM is \(L = 0.32 \text{cm}\), \(d = 3.8 \times 10^{-3} \text{cm}\), and AM gives 2.5 \(10^{17}\) induced gamma-quanta (see 2.1). The portion of super-fluorescent gamma-radiation in this case is negligibly small (see 2.2). The heat release in this AM is

\[
q = nE_\gamma \alpha/((1 + \alpha) \tau_\gamma) = 1.6 \times 10^{11} \text{W/cm}^2.
\]

(1)

At these conditions the self-consistent method gives the estimation \(T_{\text{act}} = 27.3 \text{K}\) for the quasi-temperature\(^2\) of AM. Such low temperature is obliged to the fulfillment of the condition for efficient cooling

\[
\Lambda_\gamma, \Lambda_{\text{ph}} \gg \sigma.
\]

(2)

where values \(\Lambda_\gamma, \Lambda_{\text{ph}}\) are the free paths of non-equilibrium electrons and phonons correspondingly. Indeed, for the diamond of II-a type at 27.3 K the free paths are \(\Lambda_\gamma = 8.5 \times 10^{-4} \text{cm}\) and \(\Lambda_{\text{ph}} = 0.028 \text{cm} = 737 \text{d} \gg d\). \(\Lambda_{\text{ph}} = 0.028 \text{cm} = 737 \text{d} \gg d\).

1.2 Balance energy equations for AM, self-consistent method

Balance energy equations for AM (1983.1995, Karyagin) were derived and used in works\(^2\)–\(^6\)

\[
\frac{d}{dt}Q_\gamma = q - \left( \tau_{\text{ph}^{-1}} + \tau_{\gamma^{-1}} \right)Q_\gamma,
\]

(3a)

\[
\frac{d}{dt}Q_{\text{ph}} = -\tau_{\gamma^{-1}}Q_{\text{ph}} + \tau_{\text{ph}^{-1}}Q_\gamma,
\]

(3b)

\[
q = 1.6 \times 10^{11} \text{W/cm}^2, \quad \tau_{\gamma} = 3.8 \times 10^{-3} \text{s}, \quad \tau_{\text{ph}} = 2 \times 10^{-11} \text{s},
\]

(4)

where \(Q_\gamma, Q_{\text{ph}}\) is energy-density (ED) of non-equilibrium (NE) charged carriers, \(Q_{\text{ph}}\) is the ED of NE-phonons; \(\tau_{\gamma}, \tau_{\text{ph}}\) is time of free exit of charged NE-carriers from AM; \(\tau_{\text{ph}} = \nu_\text{ph}/\nu_\gamma\) is a time of free exit of NE-phonons from AM; \(\nu_\gamma \sim 10^{8} \text{cm/s}\) is a mean velocity of charged NE-carriers with energy \(\sim 1 - 5 \text{eV}\). For a diamond of II-a-type\(^3\) sound velocity is \(\nu_\text{ph} \sim 1.6 \times 10^{6} \text{cm/s}\). Time of electron-phonon relaxation \(\tau_{\gamma}^{-1}\) is found from a trial electron-hole mobility\(^6\) \(\mu = \nu_{\text{eff}}/e \sim 1.8 \times 10^{15} \text{cm}^2/\text{V} \text{s}\). Here \(\mu\) is used in \(\text{cm}^2/\text{V} \text{s}\) and \(\tau_{\gamma}^{-1}\) in seconds. The decisions for (3a,b) are (5a,b) or (6a,b), (7) in a stationary limit \(\tau_{\gamma}^{-1}, \tau_{\gamma}, \tau_{\text{ph}}\).
\[ Q_e = \left( q / (\tau_e^{-1} + \tau_e^{-1}) \right) \left( 1 - \exp(- (\tau_e^{-1} + \tau_e^{-1}) t) \right), \] (5a)

\[ Q_{ph} = \left( q t_{ph} / (1 + (\tau_e^{-1} / \tau_e)) \right) \left[ (1 - \exp(- t / t_{ph}) - \exp(- (\tau_e^{-1} + \tau_e^{-1}) t)) / ((\tau_e^{-1} + \tau_e^{-1}) t_{ph} - 1) \right]. \] (5b)

\[ Q_e = q / (\tau_e^{-1} + \tau_e^{-1}). \] (6a)

\[ Q_{ph} = q t_{ph} / (1 + (\tau_e^{-1} / \tau_e)). \] (6b)

\[ Q_e = 0.051 \text{ J/cm}^3, \quad Q_{ph} = 0.012 \text{ J/cm}^3. \] (7)

The values (7) are achieved by the self-consistent method. The value \( \tau_e \) is a function of a quasi-temperature \( T = T_{AM} \) which at \( T < T_D \) is proportional to \( Q_{ph}^{1/4} \) with the factor 82.1 K for diamond (\( Q_{ph} \) and \( T \) are taken in \( \text{J/cm}^3 \) and \( K \)).

\[ \tau_e(T) = \tau_e(50 \text{ K}) (50/T)^{1.5} = 3.4 \times 10^{-11} (50/T)^{1.5} \text{ s} = 1.2 \times 10^8 \text{ T}^{-1.5} \text{ s}, \] (8)

\[ T = 82.1 \left( Q_{ph}^{1/4} \right). \] (9)

Substitution (8), (9) into (6) gives non-linear equations, which lead to self-consistent results (7) - (10):

\[ T = 27.2 \text{ K}, \quad \tau_e = 8.5 \times 10^{11} \text{ s} \text{ and mobility } \mu = 1.5 \times 10^5 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}. \] (10)

A more accurate procedure with the self-consistent accounting of non-equilibrium carriers in the rest part (around the AM and further) of previously cooled crystal (\( T \sim 10 \text{ K} \)) leads to a more precise estimation of quasi-temperature \( T = T_{AM} \) in AM

\[ T_{AM} = 27.3 \text{ K}. \] (10a)

Good coincidence of results (10) and (10a) shows accuracy of simple equations (3), (3a) when condition (2) is fulfilled. An active medium of solid cold \( \gamma \)-laser contains a self-microplasma (1995, Karyagin). The existence of self-microplasma was first predicted and theoretically set up in works of A. A. Soldatov. A density of charged carriers \( n_e \) is set at energy for the creation of pair of charged carriers \( \varepsilon_0 \) (13.3 eV = 2.1 \times 10^{10} J for diamond):

\[ n_e = 2 Q / \varepsilon_0 = 4.8 \times 10^{16} \text{ cm}^{-3}. \] (11)

So, it is proved that the gamma-generation is not suppressed by heat in case of SPTEN. Besides it is shown (1997) (also see 1.6) that appearance of self-microplasma is beneficial for a gamma-lasing in SPTEN-schemes.

1.3 Suppression of inhomogeneous Doppler shift in solid AM by a “heat-stress-feedback method”

A solid AM differs from active media of other aggregate states by a feasibility of method of the full suppression of the inhomogeneous Doppler shift (IDS). The IDS results from a heat expansion of AM and makes a \( \gamma \)-lasing non-realized. Suggested method consists in a preliminary moderate stress (stretch, compression) of AM-body fasten by the thermostated fixtures. In such conditions any deviation in forces due to the temperature is exactly compensated by the opposite prompt deviation of fixture stress-reaction. Otherwise, in method a deep feedback through the fixture stress-reaction is used. The use of “heat-stress feedback method” in other aggregate states is too problematically.

1.4 Developed oriented (e.g., comb-like) micro-profile (DOCLMP) of AM for effectiveness of all solid \( \gamma \)-laser types

Developed oriented (e.g., comb-like) micro-profile (DOCLMP) of AM was suggested and elaborated (1983, 1995, Karyagin) for the effective cooling of AM. E.g., DOCLMP can be engraved on surfaces of single-crystal as line row of teeth. Each tooth is characterized by transversal width \( d \), transversal high (or depth) \( h \) and longitudinal size (thickness) \( d_c \). A size \( d_c \) is measured at half of a high h. Hence the thickness at the bottom (foot) of tooth is \( 2d_e \). The distance between the tops of two nearby teeth (period of DOCLMP along active medium) is \( 2d_e \). Fullfill number of teeth is \( N_{zh} \sim L / 2d_e \). E.g., in considered case (see 1.1) \( L = 0.32 \text{ cm}, \ d = h = 3.8 \times 10^{-5} \text{ cm}, \ d_e = 1.6 \times 10^{-4} \text{ cm}, \ N_{zh} = 1.6 \times 10^5 \text{ and a fractality (denticulation)} \) is \( h / 2d_e \), = 19. A building of such DOCLMP demands to use modern micro and nano technologies.

Owing to DOCLMP the demands to pumping, \( \gamma \)-lasing and cooling (energy transfer from AM to crystal-substrate) are in compromise. In deed in order to avoid diffraction losses it is necessary to have AM with diameter (2L)^{1/2} \sim 10^{-4} \text{ cm}. Intrusion of heavy atoms to depth \( 10^{-4} \text{ cm} \) is possible only in a hard intrusion at energies \( 10^6 \sim 10^7 \text{ eV/cm}. A heat release in such case is more by 2 - 4 orders than \( q = 1.6 \times 10^{11} \text{ W/cm}^2 \text{ in eq.(1). Owing to DOCLMP it is possible to coincide a soft transplantation in 1 - 5 outer surface layers (at energy} \sim 10^5 \text{ eV) with a sufficiently big transversal size of AM} \sim 10^{-4} \text{ cm. A density of heavy atoms } n = 9 \times 10^{20} \text{ cm}^{-3}, \text{ see 1.1, leads to strong scattering of energy carriers (EC) and so to decreasing of paths } \Lambda_e, \Lambda_{ph} \text{ (see eq.(2)) lower than } 10^{-4} \text{ cm. Fortunately all working nuclei are sited at near-surface layers (boundaries of DOCLMP) and so its doesn't hinder to free exit of EC (phonons, electrons, holes) from AM. So owing to DOCLMP the paths } \Lambda_e, \Lambda_{ph} \text{ are the same as without impurities. Lastly, a big ratio } d / 2d_e \sim 50 \text{ leads to a big distances } \sim 3 \times 10^{-7} \text{ between} \)
near-hood working nuclei and so DOCLMP is necessary for line narrowing. DOCLMP is necessary element for a construction of AM in all (not only SPTEN) solid γ-lasers. More common types of DOCLMP are regarded in work 2.

1.5 Atomic (molecular) multi-beam emitters (MBE)
A more than sufficient amount of ELAN and its density in AM could be reached with help of a specific device (1983,1995, Karyagin) called as “converter” for γ-lasing or as atomic (molecular) “multi-beam emitter” (MBE) for some other scientific and practical applications 3,5,6,19. Owing to these devices with oriented deep micro-relief the effectiveness of laser isotope (isomer) separation (LIS)33,34 can be increased by some orders at keeping of LIS-quality. Such result for MBE is owed to big amount of atoms in multi-beam, preliminary its cooling and de-ionization, possibility to clean beam from ions before the LIS, weakening of both charge exchange probability and Doppler spread, compactness of device. Besides: the efficiency of LIS increases extremely by many orders if isotopes (isomers) are born in surface layers of MBE. At this case not only stable isotopes but also short-lived isotopes can be more successively separated by laser. The know-how and some equipment for MBE-development are available in Semenov Institute.

1.6 Narrowing effect of self-micro-plasma on γ-lasing in SPTEN-schemes
Free charged carriers (CC) are jumping between the host atoms with frequency \( v' \approx v_n (n)^{1/3} \approx 10^{16} \text{ s}^{-1} \). The CC are trapped by working atoms. Two types of working traps are interesting: 1. Deep traps with a long time-living \( t_w \) of trapped CC, i.e., \( t_w \gg 1/v' \); 2. Fine traps, when \( t_w \approx 1/v' \). In case of deep traps of only one type a line broadening can be small and \( \Gamma_{1} \approx 1 \), if homogeneity of crystal-chemical parameters 15 of trap environment exists at going overall AM from trap to trap. In case of many trap-types the spectrum is dispersed over many peaks multiplied by a number of HFS-peaks. Together with relaxation processes it gives a continuous spectral band with a damping factor \( \Gamma_{1} \gg 1 \) adverse for γ-lasing. In case of fine traps the working atoms are recharging, i.e., its charge-state are changing through “+”, “0”, “-”, with a frequency \( v_n, v_n' \). The line depends on the charge-state of trap and so is running through positions \( \omega_n, \omega, \omega_n \), with an amplitude \( \delta = \sup \{ \omega_n - \omega, \omega - \omega_n, \omega_n - \omega \} \). If \( \delta \ll v_n \), then one single line of a width \( \Gamma = \tau_1^{-1} + \Delta \Gamma \) arises instead of “triplet” \( \omega_n, \omega, \omega_n \). Here \( \Delta \Gamma = \Delta n_v \approx (\Delta n)^{1/3} / (2\pi v_n) \). The broadening \( \Delta \Gamma \) can be decreased by the selection of AM (nucleus, substratum) or by regulation of heat-radiate regime, through the changing parameters \( \delta, n_v, n_n \). At a fortunate selection of AM or its parameters it could be reached the effect of spectral “collapse”, i.e., the contraction of all lines of an inhomogeneous spectrum with its HFS into one tight singlet with a natural width \( \Gamma_1 \approx 1 \). This effect is beneficial for γ-lasing, especially in cases \( \tau_1 > 10^{-4} \text{c} \), \( \tau_1 > 10^{-4} \text{c} \) (but not for too big \( \tau_1 \)). This narrowing effect was verified. E.g., in the low-temperature samples (saturated with hydrogen) the narrowing of lines and its collapse into narrow singlet were revealed when temperature was increasing 13.

E.g., for AM of type \( ^{58}\text{Co}/\text{Di} \) at \( T_{\text{AM}} = 90 \text{ K} \) the appropriate values are: \( n_n \approx 5 \times 10^{18} \text{ cm}^{-3} \); \( v_n \approx 10^{16} \text{ s}^{-1} \); \( v_\nu = v_n, v'_n, n_n \approx 10^{11} \text{ s}^{-1} \). Let \( \delta = 6.3 \times 10^{-5} \text{ s}^{-1} \); then \( \Delta \Gamma = \delta^2 / 2v_n = 6.7 \times 10^6 \text{ s}^{-1} \). A \( \text{spectrum} \) bands of width \( \delta = 6.3 \times 10^{-5} \text{ s}^{-1} \) (without plasma) is collapsed into \( \text{single line} \) of width \( \tau_1^{-1} + \Delta \Gamma \), where \( \Delta \Gamma = 6.7 \times 10^6 \text{ s}^{-1} \). Another words, a spectral band with adverse factor \( \delta = 985 \) is collapsed into line of natural width with a broadening factor \( \tau_1/\Delta \Gamma = 0.1 \). So \( \tau_1/\tau_1 = 1 \), see ch.2.

2. REAL GAMMA-LASING CONDITIONS

2.0. Effects of distance on γ-lasing or alias the «Width-Path Effects» (WPE) or alias «L'-effects». For the initial stage at \( t << T_2 \) amount of γ-quanta in a lasing mode is small, a phase is absent, propagation of photons could be regarded separately from others and a total spectral width \( \Gamma_{tot} \) in γ-lasing mode is (width-path effects, WPE, see 2.1, 2.2).

\[
\Gamma_{tot} = \tau_1^{-1} = \Gamma + \Gamma(L, \tau_1), \quad \Gamma(L, \tau_1) = (\tau_1 + L'/c)\Gamma.
\]

(12)

Here \( \Gamma = \Gamma_h + \Gamma_{ih} \) is a standard total width, \( \Gamma_h + \Gamma_{ih} \) is a sum of homogeneous \( \Gamma_h \) and heterogeneous \( \Gamma_{ih} \) widths 15,16. A term \( \Gamma(L', \tau_1) \) depends on free path of photon \( L' \). Path \( L' \) is a length along eikonal of photon from place of its arising to a place of its exit from a lasing mode. A photon is vanishing for a time \( \tau_1 \) in resonant or non-resonant absorption and scattering. For resonant processes \( \tau_1 = \Gamma^{-1} \), for non-resonant ones \( \tau_1 << \Gamma^{-1} \). A sum \( \tau_1 = \tau_1 + (L'/c) \) is a “time-life” of photon in lasing mode. In rise only \( 1/\Gamma_{tot} \) of photons induce emission. All resonant probabilities must to include “filtering factor” (see 2.1.2.2).

\[
1/\Gamma_{tot} = \tau_1/\tau_1 = (\tau_1/\tau_1)\Gamma w/(1 + \alpha),
\]

(13)

A vanishing of photon (not only in a detector) interrupts any interaction with it for the time \( \tau_1 \) that is accounted in γ-lasing not only through the “filtering factor” (width-path effects, WPE, see 2.1, 2.2).

The time \( \tau_1 = 1/\Gamma_{tot} \) is less than standard time \( T_2 = 1/\Gamma \) (which is used widely) because always \( \Gamma_{tot} > \Gamma \); In optic lasers due to n-fold reflection of photon by mirrors the nominal sizes of optical device are sufficient to have \( L' > 10cT_2 \) and so \( \Gamma < 0.1\Gamma_{tot} \). \( \tau_1/\tau_2 > 1.1 \). But at non-resonant detector in mirror-less γ-laser \( \Gamma < 0.1\Gamma_{tot} \) only at long distance \( L' > 10cT_2 \) between its exit-plate of γ-laser and the detector (or absorbing target). E.g., \( \tau_1/\tau_2 > 1.1 \) for \( ^{58}\text{Co} \) if a distance \( L' > 4.5 \times 10^6 \text{ cm} = 45 \text{ km} \). These “width-distance effects” (L'-effects, Width-Path Effects) are accounted below in sec.2.1, 2.2. In Mössbauer effect experiments a vanishing time is \( \tau_1 = \tau_1 \) due to big duration of resonant absorption (scattering) 28. So \( L' > 5 \text{ cm} \) in other to observe the L'-effect on
line width. Deformation of line-form by apparatus depends on a distance \( L' \) too. So \( \Gamma = \Gamma_{ob}(L') \cdot \Gamma_{gal}(L') \cdot \Gamma \), where \( \Gamma_{ob}(L') \) is an observable line width, \( \Gamma_{gal}(L') \) is apparatus broadening, and a "subtraction" indeed is the deciding of rolling-type equation

\[
I_{ob}(\omega) = \int_0^\infty I(\omega') A(\omega-\omega') d\omega'.
\]

I.e., to execute in deal subtraction \( G_{ob}(L') \cdot G_{gal}(L') \) means to find a true (non-deformed) form of Moessbauer line \( I(\omega) \), if the form \( I_{ob}(\omega) \) and kernel \( A(\omega-\omega') \) are the well-known functions of frequency \( \omega \). Here \( I_{ob}(\omega) \) is the observable line-form and the kernel \( A(\omega-\omega') \) is the apparatus function. A more general form than equation (14) is a linear integral transformation

\[
I_{ob}(\omega) = \sum_\mathbf{r} \sum_\mathbf{r'} \sum_\mathbf{k} \sum_\mathbf{k'} \rho(\mathbf{r}; \mathbf{r'}, \mathbf{k}; \mathbf{k'}) A(\mathbf{r}, \mathbf{r'}, \mathbf{k}, \mathbf{k}; \omega, \omega') \tilde{d}^\mathbf{r} \cdot \tilde{d}^\mathbf{r'} \cdot \tilde{d}^\mathbf{k} \cdot \tilde{d}^\mathbf{k'},
\]

where \( \mathbf{r} \) is start point of emitted photon in source; \( \mathbf{r'} \) is finish point of this photon in detector; \( \mathbf{k}, \mathbf{k'} \) are wave vectors in source and detector, respectively; \( \mathbf{k}, \mathbf{k'} \) are the final (in detector) ones; \( \omega, \omega' \) are the photon energies in source and detector; \( r, r' ; k, k' \) are the coordinates of initial and final photon points, respectively. The transformation of rolling-type (14) can only to broaden natural line, but it can't to narrow line \( I(\omega) \). In contrary to it a general transformation (15) can make both: to narrow and to broaden form of line. In deal, a line more narrow than natural one could be got in n-fold Bragg resonant scattering, at some superposition of resonant filters, or in case of amplification. So, there are no evidence for a new effect even if observable line \( I_{ob}(\omega) \) is more narrow than a natural one. The width-path effect (12) doesn't change the spontaneous time \( \tau_1 \). But it needs be accounted in analyses of \( \gamma \)-lasing (see 2.1, 2.2) and some trials. A significant part of "shielding-effects" (SE) can be conditioned or masked by width-path effect (12) and by a disregarding with a general relation (15). Note two remarks: 1. - A zero-field-nucleus interaction can't to change essentially an internal electron conversion probability. So a new "shielded" natural time-life \( \tau_1 \) can't be more than \((1 + a) \tau_1 \). 2. - In a strict quantum theory any real value (e.g., width) needs to be variable to orthogonal normalized (ON) changes in ON complete base of self vectors (functions, modes). SE-theory breaks this law and hence leads to artifact.

### 2.1 Real threshold conditions (RTC) for induced gamma-oscillation in DOCLMP

The parameter \( p \) of "reserved amplification" (RA) is introduced through a formal balance equation

\[
n \sigma_0 \gamma_2/\gamma_1 = p (n \sigma + n' \sigma'),
\]

where \( n = n_s + n_n \), is a total density of working nuclei amount (DWN) averaged over tooth volume; \( n_s \) is DWN for a level \( +\); and \( n_n \) is DWN for a level \( -\). This is a definition of RA. The value \( L_0 = (n \sigma + n' \sigma) \) is length of non-resonant losses in substance of tooth. Appropriate value in DOCLMP equals \( 2L_0 \). Formally \( RA = (\gamma_2/\gamma_1)n_\sigma L_0 \) is a gain on length \( L_0 \). The definition RA (16) is only a handy combination of basic values and isn't a real balance equation. n.s. \( \sigma \) and the induced cross-section reach limit \((\gamma_2/\gamma_1)n_\sigma \) only at time \( t >> \tau_{5.27} \). RA is estimated from a complex of conditions below. By (16) RA has a maximum \( p_0 = \frac{\sigma_0}{\sigma} \gamma_2/\gamma_1 \) where \( \sigma_0 = \gamma_2/\gamma_1 = 888 \) for \( ^{58}\text{Co} \). Another basic value is a density \( n' \) of host-atoms. For a diamond \( n' = 1.76 \times 10^{23} \text{ cm}^{-3} \). The relative impurity concentration \( n/n' \), a value \( \psi \), total length \( L \) of DOCLMP, relative length \( y = L/2L_n \), amount of diffraction modes \( m \), all data in 1.1 are the departure values in estimates. Then the lesser values are derived: RA: cross-size \( d \) of AM; volume of AM \( V = d^3 \) (for a square form of AM cross-section); solid angle \( \Omega \) of diffraction mode; total number \( N_0 = nV/2 \) (half of comb-like AM is empty) of working nuclei; resonant cross-section \( \sigma_0 \), i.e.

\[
\gamma = (n')/(n' + (\sigma' \omega)); L_0 = (1 - \psi)/(n' \sigma); L = 2yL_0; p = \psi p_{2/(\gamma_2/\gamma_1)}; d = (nL)^2; \gamma = 4(L_0)^2 m \lambda; \Omega = \pi L;
\]

\[
N_0 = 2 (m \lambda h' \sigma') \psi (1 - \psi) \gamma^2;
\]

\[
\sigma_0 = (2^2/2\pi) f\omega/(1 + \alpha).
\]

The number of \( \gamma \)-quanta arisen in the amplification of stimulated emission (ASE) at account of width-path effects is

\[
N_A(p) = (N_0 y) \int_0^{\infty} e^{2x} dx [\exp([G(x') - 2 ] y_{\gamma} - 1)] / [G(x') - 2].
\]

In usual case of a non-resonant detector the negative part \(-2\) of the \( pG \) \((pG - 2)\) contains two parts: the first ordinary part \(-1\) to the direct non-resonant losses and the second equal but unusual part \(-1\) owing to the non-direct influence of the same non-resonant losses but through the introduced above \( \gamma \)-Width-Path Effects which particularly decreases the resonant cross-section.
Without WPE the «gains» would be \( pG - 1 \). Here \( x = t/r \); \( N_0 = (p/n_0) \exp(x_i) \) is a number of spontaneous \( \gamma \)-quanta emitted for all time in \( m \) modes in a spectral interval \( \tau_i^{-1} \); \( \exp(x_i) = n_+(0)/n_0(n_+(0) is ELAN amount density at momentum \( t = 0 \). A value \( pG(\gamma)/L_0 \) is a generalized induced gain. According to \( 19, 16, 9 \), a cross-section of induced emission \( \sigma(t) \) equals to zero at the start momentum \( t = 0 \), when a resonant interaction (ELAN and a gamma-radiation field) is switched. The value of \( \sigma(t) \) asymptotically grows up to its limit \( \sigma(\infty) = C_0 \) during time \( \tau \). A correct formula for \( \sigma(t) \) is not yet derived because of difficulties in transforming of complicated non-linear decisions of Maxwell-Bloch equations to cross-section concept. As a compromise, a simple approximate formula containing all properties marked above was suggested and used in works \(^{5,8,8-9} \) for the quick evaluations:

\[
\sigma(t) = (1 - \exp(-t/\tau_i)) \frac{\sigma(t)}{\sigma(\infty)}. \tag{21}
\]

Hence a stationary formula \( pG/\sigma = (n_+ - g n_+/r \tau_i) \sigma \) for induced gain need be transformed to the next more complex form

\[
pG(t)/L_0 = n_i(t) \sigma_i(t) - \frac{\sigma_i(t)}{\sigma(\infty)} + \int_0^t n_i(t') \sigma_i(t-t') \, dt'(\tau_i). \tag{22}
\]

Here \( \sigma_i(t) = \sigma_i(\infty) (1 - \exp(-t/\tau_i)) \) is \( \sigma(t) \) for emission from \( \infty \) to \( t \) state; \( \sigma_i(\infty) = (\tau_i/r \tau_i) \) is a limit for \( \sigma_i(t) \) at infinite time. By analogy \( \sigma_i(t) = \sigma_i(\infty) (1 - \exp(-t/\tau_i)) \) is \( \sigma(t) \) for the transition from \( \infty \) to \( t \) state; \( \sigma_i(\infty) = (\tau_i/r \tau_i) \) is a limit for \( \sigma_i(t) \) at infinite time. In common case a value \( g \) can be different from \( (2j_i+1)/(2j_i+1) \). E.g., \( g = 0 \) in case of ideal AWL (ch.3); \( g = 1 \) in case of non-degenerated working levels. The nuclei arise spontaneously in a lower state \( \infty \) at momentum \( t \) are dephased at this time-point \( t \). So at \( t > t \) a phasing time \( t_0 \) of these nuclei (or time of growing of its absorption cross-section) is \( t_0 = t - t \). The value \( n_i(t') \, dt'(\tau_i) \) is a number of «new» nuclei in state \( \infty \) in the time-interval \( dt' \). In case of weak generation the populations \( n_i(t) \) and \( n_i(t) \) are

\[
n_i(t) = n_i(0) \exp(-t/\tau_i), \quad n_i(t) = n_i(0) + \int_0^t n_i(t') \, dt'(\tau_i). \tag{23}
\]

A time-dependent factor \( G(t) \) of induced gain function is transferred to the form (25) at a formal denoting (24):

\[
G(t) = (1 - \exp(-x_i + r/\tau_i)) \left( \exp(-x_i - x) + g \exp(-x_i) \right) \left( e^{-x} - \exp(-x/\tau_i) \right) / (1 - (r/\tau_i)); \tag{25}
\]

or else (see below) at denotations \( \mu = e^x \) and \( \xi = (r/\tau_i) \) ones have

\[
G(t) = G(\mu(\xi)) = (1 - \mu^x) \left( (1 - \mu^\xi) + g \mu \right) \left( 1 - \xi \right) \tag{25#}
\]

Note that the limit of \( G(t) \) at \( \xi = (r/\tau_i) \rightarrow 1 \) is a function \( \lim_{\xi \rightarrow 1} G(t) \approx t_2/r_2 = 1 \) estimated as

\[
G_{lim}(t) = (1 - e^{-x} + g \exp(-x_i - x) - g (1 - e^{-x}), \tag{25a}
\]

Here (25a) corresponds to a particular case \( r_1 = r_2 \). The decisions (25), (25a) satisfy for all initial and limit cases. The further analysis is based on the approximation of \( G(t) \) by a quadratic form \( G(\mu) \approx G_\mu - (1 - \mu^x) K \), where \( \mu = e^x \). The values \( G_\mu, K \) depend on basic parameters \( r_1/r_2, g, e^x \). Poisson's formula leads to

\[
N_{\sigma}(p) = (n_0^2/m^2) (n_0/\gamma)^{1/2} \left( \frac{m \gamma^2}{m - 1} \right) \tag{26}
\]

Here the negative part \( -2 \) of the «gains» \( (pG_\mu \rightarrow 2) \) contains two parts: the part \( -1 \) owing to the direct non-resonant losses and the another equal parts \( -1 \) owing to the non-direct influence of the same non-resonant losses but through the introduced above «width-path» effect action. Eq.(26) is approximately valid \(* \) at \( pG_\mu \rightarrow 2 \) and contains threshold condition for ASE: \( p > 2G_\mu \). The more precision expression at \( pG_\mu \rightarrow 2 \) is omitted in this short report but will be published in another more special work devoted only to the induced radiation. The roots of equation \( G(\mu) = 2/p \) are \( \mu = \mu + \Delta(\mu) \), \( \mu = \mu - \Delta(\mu) \), where \( \Delta(\mu) = (2G_\mu - 2)/(2G_\mu - 2) \). The factors \( \mu \) instead of \( 1 \mu \) in (26) are due to the above Width-Path Effects. The start-time for \( \gamma \)-lasing is \( t_0 = -r_1 \mu \). The end-time for \( \gamma \)-lasing is \( t_0 = -r_1 \mu \). At \( t < t_0 \) and \( t > t_0 \), \( \gamma \)-lasing is absent. Time-interval of ASE-generation is \( t_0 \rightarrow t \) with duration \( t_0(t) = t - t_0 \). Eq.(20), (26) with \( p > \gamma \mu \) give an upper limit of \( N_\sigma \). The substitution of decision \( p^* \) of equation \( p^* = t_0(2)/(2T_0) \) (instead of \( p \)) to (20), (26) gives a lower limit for \( N_\sigma \). Here \( t_0 = t_0(p^*) \). Factor \( t_0(2)/(2T_0) \) over-accounts a frequency band \( ~2(2T_0)^{-1} \) of \( \gamma \)-pulse. The real value \( N_\sigma \) is inside interval \( N_{\sigma}(p^*) < N_\sigma < N_{\sigma}(p) \). A peak energy

\[**a** \nIn the SPIE-paper the eq. (26) was contained the incorrect factor \( m/\gamma \) which was changed here into the true value \( m/4 \). This formula is approximately valid at \( pG_\mu \rightarrow 2 \) or \( \gamma > 0.5 \), i.e., in more wide region than the adequate formulae of Ref.[36]. The formula valid at \( pG_\mu \rightarrow 2 \) or \( \gamma > 0.5 \) is located in the main text of the Present Work and will be published in a further work which is in a progress.
flow \( I_s \) equals (at appropriate \( p \) or \( p^{*} \)) to the integrand of (20) multiplied by \( E_s/(E_s^2) \). A peak saturation parameter \( P_s = \tau_s \sigma_s E_s \) is also used below.

**Numerical examples.** According to data of 1.1 there are the next values: \( \gamma/\tau_s = 1.1; \exp(-\chi_0) = 0.9; \ n/n' = 5 \times 10^{-2}; \ \sigma'/(\gamma - \sigma) = 4.7 \times 10^{-5}; \ \psi_0 = 0.515; \ L = 0.321 \ cm; \ y = 0.329; \ d = 3.8 \times 10^5 \ cm; \ p = 416.5 >> p_0 = 2 G_m = 14.5. \) \( p_0 \) is a threshold. So it is a super-threshold \( \gamma \)-lasing. Note, that necessary short period \( t_i \), \( \sim 10^{-5} \) s of ELAN-implantation is in touch in SPTEN-method. Besides, the prompt shatters with \( t_i \), \( \sim 10^{-5} \) s could be created. Other parameters are: \( G_m = 0.138; \ \mu_0 = 0.705; \ K = 1.586; \ \Delta = 0.290; \ \mu_\alpha = 0.995; \ \mu = 0.345; \ t_s = 5 \times 10^5 \ \tau_s = 7.6 \times 10^5 \ \mu_s = 0.087 \ \chi_0 = 1.33 \times 10^5 \ \mu_s = 0.35 \ \tau = 3.3 \times 10^6 \ \mu = 0.087 \ \chi_0 = 1.32 \times 10^5 \ \mu_s = 0.2. \) The next pulse characteristics are: \( T_s = 10^{-3} \ \chi_0 < N < 1.3 \times 10^5; \ 5 \times 10^{-12} < N < N_0 < 6 \times 10^6 \ \mu_s = 0.35 \ \tau = 3.3 \times 10^6 \ \mu_s = 0.087 \ \chi_0 = 1.32 \times 10^5 \ \mu_s = 0.2. \)

2.2 Real threshold conditions for the super-fluorescent (super-radiant) gamma-oscillation based on the approximate theory in case of the strong varied length of Bloch’s vector.

The decision \( R_3 \) for the projection \( R_3 \) of Bloch’s vector \( R \) had been generalized (1995, 1998, Karyagin) for non-keeping \( R \). \( R_3 = \frac{R \ (R - e^{\psi} \psi)^{\psi}}{R + e^{\psi} + \psi}. \) (27)

Here \( R = R' \ D_{ph} \ (\tau_0/\tau_s) \) is the length of effective time-dependent Bloch’s vector. \( R' = (z e^{\psi} - g) N_0 \) is a time-dependent ordinary inverse vector in AM generalized on common case of arbitrary nuclear state degeneration, see 2.1. Value \( R' \) depends on \( x = \tau/\tau_s \) and \( z = (1 + g) \exp(-x_0). \) Factor \( D_{ph} = 1 - (1 + \gamma) c \gamma \) is an effectively phased relative part of all nuclei in the active medium at the totally reliable event that the spontaneously emitted \( \gamma \)-quanta are emitted in one axial generation mode. \( \gamma = \frac{1}{2} L_{L_0}. \) Values \( p, w, f, \alpha, \chi_0, \tau_s, \chi_0, \chi \) see in 2.1. Time \( \tau_s \) depends on length \( L \), see Width-Path Effect in the beginning of sec.2 and in 2.1. The factor \( D_{ph} \) accounts the loss of photons from phasing process. That loss is owed to scattering or non-resonant absorption in AM. The speed of transitions \( \tau_0 = (1/2) (\Omega/4 \pi \omega) (\psi \psi_0 \tau_0/(1 + \alpha) \tau_0) \) is the probability (in \( s^{-1} \)) of the event above that the \( \gamma \)-quantum is spontaneously emitted just in the axial generation mode. The factor \( 1/2 \) accounts the two polarizations; the solid angle of the first diffraction mode is \( \Omega = \pi \). The length \( L = 2L_0 \psi \) in case of a dispersed active medium is twice in a comparison with the usual active medium: the resonant cross-section averaged over all polarizations, directions and HFS-components is \( \sigma_o = (\lambda^2/2 \pi) (w f / (1 + \alpha) \psi \psi_0 \tau_0/\tau_0) \); the formal gain factor \( \psi / \pi \pi_0 \psi_0 \tau_0 \). In sec.2.1, the square of the transverse section of the active medium is \( \sigma^* = \sigma \), the volume of the active medium is \( V = \pi_0 \psi \), the total number of work nuclei (excited and non-excited ones together) \( N_0 = (1/2) \psi \) because the dispersed active medium is a half-empty one. The accounting of all relations above leads to the simple equivalent form \( (1/\psi_0) = (w f / (1 + \alpha) \psi \psi_0 \tau_0) \). Hence \( \phi_0 = (4N_0 \psi_0 / d) \psi \psi_0 \tau_0 \phi_0 \) is the time of the spontaneous emission per one nucleus into the generation mode; note that \( \tau_0 >> \tau_s \). The selection of photons for phasing in tight band \( 1/\tau \), is accounted in \( \psi_0 \) by the factor \( \phi_0 \). Such factor is absent in more simple old formulas. Because of it that old simple formulas overestimate SF-part in \( \gamma \)-lasing. The main term of dephasing loss \( \tau_0 \phi_0 \psi_0 \tau_0 \) is introduced in accordance with work. It is necessary to fulfill the threshold condition \( R_3 \psi_0 \phi_0 \phi_0 \phi_0 \) \( \phi_0 \), which at \( D_{ph} \) = 1 coincides with Andreev’s condition. A number of effectively phasing "priming" photons for a time \( t \) is

\[ \psi = \int_0^t (R'/\phi_0) dt = \int_0^t ((R/D_{ph}/\phi_0 - \phi_0^2) dt. \] (28)

The "feedback" phasing addition from the super-fluorescent pulse in axial mode is

\[ \psi' = \int_0^t (\psi/\tau_0) \ I_{sf} \ dt = \int_0^t (\delta_0^2/\psi_0/\tau_0^2) dt. \] (29)

where width \( \tau_0^2 \) is a logarithmic derivation of function \( \psi_0 \) and \( \psi_0^2 = w/(1 + \alpha) \psi_0 \) is a radiation width. So \( \psi = (\psi/\phi_0) I_{sf} \) and the integrand in (29) is proportional to \( I_{sf} \psi_0^2 \). This procedure (1995, 1998, Karyagin) is approximate equivalent of averaging of resonant interaction "radiation-ELAN" over a time-depending frequency distribution of \( \gamma \)-pulse, evaluated as a Fourier from
pulse-form cut after momentum t. In a derivation $d\mathbf{R}_t/dt = C_1 + C_2 + C_3$ the term $C_1 = - R (\mathbf{R}^2 - \mathbf{R}_t^2)/(2 \tau_{\text{mod}})$ coincides with a right part of standard Bloch's equation. By analogy with it, it gets

$$I_{\text{SR}} = (R^2 - \mathbf{R}_t^2)/(2g+1) \tau_{\text{mod}} = 2R^3 e^{i\phi}/[(g+1)(R + e^{i\phi})^2 \tau_{\text{mod}}].$$

(30)

Term $C_2 = d\mathbf{R}_t/dt = d\mathbf{R}/dt$ is a natural addition to $C_t$ from inverse population decay and needs to be adopted in generalized Bloch’s equation. Term $C_3 = -(1/2) (1 - \mathbf{R}_t/\mathbf{R})^2 d\mathbf{R}/dt$ has no apparent nature and can be understood as a deflection from exact equation $d\mathbf{R}_t/dt = (\mathbf{R}^2 - \mathbf{R}_t^2) \mathbf{R}/(2 \tau_{\text{mod}}) + d\mathbf{R}/dt$. At $x < x_0$ a relation $|C_1| + |C_2| > |C_3|$ is valid; $x_0$ is a root of equation $R(x) = 0$. An approximate decision (26) satisfies to initial condition $R_0(0) = R(0)$ and to asymptotic condition $R_0(\infty) = -R(\infty)$. A maximum of function $I_{\text{SR}}$ is achieved in point $x = x_m$, in which $R(x) = e^{i\phi} + e^{i\phi}$. The analysis leads to the next algorithm in order to estimate the amount of $\gamma$-quanta in a super-fluorescent (super-radiant) pulse.

I. To introduce the three parameters which are independent on the relative length $y = L/2L_0$

$$A_1 = (p/4) x; A_2 = (n/4) g; A_3 = 4 N_{\lambda 0}/p$$

where $N_{\lambda 0} = N_{\lambda 0}/y^2 = 2(l/\lambda n^2 \sigma c)\psi(1-\psi)$, see part 2.1.

II. To estimate the argument $y$ and its functions

$$y = [1 - (1+y)e^{-y}]/y; G_1 = (\beta/y) A_1; G_2 = (\beta/y) A_2 + (\tau_1/\tau_2); K^2 = y A_3.$$ Note that $K = (4N_{\lambda 0}/yp)$ but $N_{\lambda 0} = y^2 N_{\lambda 0}$. I

III. To introduce the argument $x = x_t/2\tau_1$ and its functions $R(x) = K [G_1 e^{-x} - G_2]; q(x) = G_1 (1 - e^{-x}) - x G_2; \xi(x) = e^{i\phi}$. The region of $x$ in which $R(x) > 0$ and $q(x) > 0$ is determined by the conditions $x < x_n = \ln(G_1/G_2)$ and $(G_1/G_2)(1-e^{-x}) > 0$.

IV. The majorant for the formula (29) $\phi_{\text{maj}} = 21[n(1 + \ln(\xi_n)/2e) - 4(1+\xi)] > \phi^*$ leads to the simple approximate results $\xi_{\text{maj}} < e^{(\gamma^*) < \xi_{\text{maj}} = 31.5; R(x_m) < R(\xi_{\text{maj}}) = \xi_{\text{maj}} = 31.5; \xi_{\text{maj}} = \xi(\gamma) = \ln[G_1/G_2(R+R_K)]$.

$$N_{\lambda 0} < N_{\text{SR maj}} = N_{\lambda 0} \xi_{\text{maj}}(\xi_{\text{maj}}) = (1 - e^{-\xi}) y^{-1}(1+\xi)^{-1} \xi_{\text{maj}}(\xi_{\text{maj}}).$$

(31)

Numerical example for Co$^{58}$: $E_p = 28.1$keV; $g = 9/11$; $\exp(-x) = 9.7$; $\tau_1 = 1.1$; $\tau_1 = 1.166; \tau_2 = 2416; N_{\lambda 0} = 1.85 \times 10^{12}; A_1 = 170; A_2 = 85.1; A_3 = 1.78(10)$. In case $n/n' = 0.005; n = 8.8 \times 10^{10} \text{ cm}^{-2}; N_0 = 3 \times 10^{11}; y = 0.402; \beta/y = 0.154; g: G_1 = 26.3; G_2 = 14.2; K^2 = 7.16 \times 10^9; x_n = 6.616 \times 326.97; x_m < x_{\text{maj}} < 0.6; \xi_{\text{maj}} = 28.5; \xi_{\text{maj}} = 900; N_{\lambda 0} < N_{\text{SR maj}} = 400; N_{\text{ASE}} = 9.6 \times 10^5; N_{\text{SR ASE}} = 4.2 \times 10^7; N_{\text{ASE}} = 42$. Calculations show that in the induced super-threshold regime $N_{\lambda 0} < N_{\text{SR}}$ at the same parameters of active medium for SF and ASE. Only for a weak near-threshold regime (when $N_{\lambda 0} \approx 10$) could be $N_{\lambda 0} > N_{\lambda 0}$, i.e., so-called “weak SF”.$^3$ The results of ch.2 are more realistic than ones of simple theories.

3. SELECTIVE RESONANT PUMPING CASE

3.1 Resonant activation of ELAN

The SPTEN secures the most soft effects of both radiation and heat on AM. On the further places towards soft action on AM are all cases when parents of ELAN are preliminarily sited in AM. That parents could be transformed into ELAN by many methods of exposure of parent-nuclei by fluxes of different (non-charged or charged) particles from the various sources.$^{1,16}$ Among this manifold (without SPTEN) the methods of selective resonant pumping$^{3,8,16}$ (SRP) have the most big efficiency factor and could provide a pumping with rather soft heat-radiation AM-regimes. But towards soft action on active medium SRP is only on the second place after SPTEN among all manifold of $\gamma$-lasers.$^{4,5}$

In case of SRP a beam-flux of resonant $\gamma$-quanta $F \approx 27/c_0 \approx 3 \times 10^{18} \text{ cm}^{-2}$ is necessary in order to create a marked amount of ELAN in AM. Here the time-dependence of $c_\gamma$, see eq.(21), and duration of SRP-pulse-pumping $t_p \approx 0.1 \tau_1$ were accounted. Due to resonant absorption this flux is a fast decreasing function of length, if a flux-direction coincide with a longitudinal direction of AM. So in this case AM could be created only when $L << L_0$. But the ratio $y = L/L_0 << 1$ is not effective for $\gamma$-lasing, see 2.1 and 2.2. Hence the transversal or interim type of SRP is necessary. In interim case a part of AM cold be in the sufficiently good thermal conditions. But a rest part of AM could be heated so as in a hard transversal pumping. So the latter is sufficient to regard. A typical case of $^{58}$Co in diamond, see 2.1, is regarded below without loss of proof-community.

A region of crystal-cooler exposed by SRP-beam has cross dimensions $d \times L \approx 4 \times 10^{-5} \times 0.32 \times 0.32 \times 0.32 \times 10^{-5} \times 0.32 \times 10^{-5} = 4 \times 10^{-5} \times 0.32 \times 10^{-5} \times 0.32 \times 10^{-5} \times 0.32 \times 10^{-5}$ cm$^3$ contained in a crystal. The heat-release in such exposed "plate" (owed to photo-effect on host atoms) is $q_p \approx F \sigma E_n \ln t_p \approx 10^{11} \text{ J/cm}^3$. So $q_p \approx q$, see eq.(1), but condition (1) is strongly broken, because transversal (relative to main heat-flux from AM) sizes are big: $L_0 \approx \pi A_{\text{ph}}$. Use of self-consistent method, see 1.2, the quasi-temperature of "plate" and around AM $T_p \approx 700 - 750$K is estimated. It decreases paths $A_p \approx 5.9 \times 10^6 \text{ cm}^3$ and $A_{\text{ph}} \approx 2.8 \times 10^6 \text{ cm}^3$ as $d$. As a result the speed of energy exit from AM is suppressed by factors $f = \exp(-d/A_0); f_0 = 0.0015$ (for electrons) and $f_{\text{ph}} = 10^5$ (for phonons). So SRP adiabatically isolates AM from cooler and AM explodes before $\gamma$-lasing. The situation can be changed by Borrmann effect$^{1,2,10,16}$ at coupling factor $K = 10^6 - 10^8$. Note, that in fast pumping and $\gamma$-lasing all AM of other types (plasma, gas) are always adiabatically isolated.

3.2 Schemes of amplification “with” and “without” inversion

Note that a selective pumping needs to use schemes for inversion$^{1,2,10,15}$ or for amplification without inversion$^{1,2,10,12}$ (AWI). But (see 1.2.1.6) the active medium of gamma-laser differs from the substance of the Moessbauer sources with the significant concentration of the charged carriers: electrons and holes.$^{5,7,9}$ Its typical values are about 10$^{16} - 10^{18}$ cm$^{-3}$ (e.g., for $^{58}$Co/Di). At this condition all electronic and nuclear hyperfine structure (HFS)-levels are in strong stochastic motion and are mixing


(see 1.6). Hence it is important to provide the steadiness of inversion and AWI schemes to the charge exchange (CE). AWI-schemes\(^2\) (1980.Karyagin) are steady to CE. Its base is stability of electron-state configuration in superposition of optical fields to stochastic influence of atomic environment on HFS\(^2\). Sorry, a visual model in that class\(^2\) is stable to recharging only for “chemical-crystal narrowing”\(^1\). This simple AWI is based on selective induction (SI) of optical transition only for atoms (ions) with working nuclei in ground state (WNGS). At such SI the electronic state (ES) of atoms (ions) with ELAN remains unchanged, whereas the ES of atom (ion) with WNGS is converted into a mixture state (e.g., Ruby state) dependent on dynamics of transitions.\(^2\) As a result the gamma-absorption line is shifted in frequency relative to the \(\gamma\)-emission one. So AWI arises.\(^2\) Note, that at 1980 the word “AWI” was not exist. Instead of it was used the term “optical division” in time of single pumping process into two: excitation of nuclei and damping of self-absorption.\(^2\)

4. DIFFICULTIES OF NON-SOLID GAMMA-RAY LASERS

The solid model\(^1\) was foregone with testing of non-Moessbauer AM creation on base of Marcuse’s effect. Some difficulties revealed in that way must be accounted in modern researches, e.g.,\(^3\)

For \(g\)-lasing in solid plasma (SP): The ends of AM are spreading more quickly than its middle. A speed-difference between the ends is \(|\Delta V| > 10^5\) cm/s. For \(E_x \sim 100\) keV it leads to Doppler width \(\Delta V \sim |\Delta V|/c > 10^4\) cm/s and to unreality of \(g\)-lasing on SP (cf. 1.3). Besides: The losses of \(g\)-lasing owing to its scattering on free electrons of plasma needs to be accounted.

For beam \(g\)-lasing (BGL). There is a row of steps 1-9 in order to qualitatively estimate a beam \(g\)-lasing (BGL).

**Step 1.** Suppose, that gas-AM is somehow cooled. Let at time \(t = 0\) all atoms in beam have equal speeds. But it is impossible to transform mixed ionized atomic beam in a gas-lattice with equal inter atomic gaps along AM-axis. The gaps \(r\) are spread around \(r_e = n^{1/3}\) with dispersion \(|\delta r| \sim r_e\). In gas-AM electrons (see below) are adhered and so Debye shielding is not valid at fast resets. Interactions of atoms and ions are not strongly shielded in such gas even at formal Debye radius \(r_D < < r_e < < r\): interaction energy \(U(r)\) is random and dispersion of axial atomic speed for \(t > 0\) is \(\Delta V_e \approx \hbar/M |\delta U/\delta r|^\gamma|_0\). Account of Doppler broadening condition \(V_j/\omega_c < 1/\zeta_0\) leads to

\[
|\delta U/\delta r|^\gamma|_0 \approx \hbar \alpha_c/c/\zeta_0 \omega_c
\]

where \(\zeta \sim 1\) for atomic beams, but \(\zeta < < 1\) for free nuclei beams (step 6); \(\gamma \tau = \tau_0\) is a time of acceleration of marked atom in field of nearest neighbor. Here \(m_e = 1.67 \times 10^{-24}\) G is an atomic-mass number: \(\omega_c = 1.52 \times 10^{16}\) E\(\times s^{-1}\) is a frequency of \(g\)-quantum (\(E_g\) is in keV). The gas-AM is saturated by ions, because internal conversion initiates creation of Auger electrons \(\sim 10^{-10}\) and secondary ones \(\sim 10^{-2} \sim 10^{-3}\) which adhere to atoms or to walls. At \(t < 10^{-6}\) s the concentration of “+” and “-” ions in gas-AM is \(C_i > 10^{-3}\). For a free nucleus beam \(C_i = 1\). The polarization by ions enhances interaction of atoms with environment. Averaging over neighbor pairs: atom-atom, ion-atom, ion-ion gives \(|\delta U/\delta r|^\gamma|_0 \approx e^2/nK_e\). Here \(e\) is elementary charge \(4.8 \times 10^{-10}\) CGSE, \(n\) is a density-amount of atoms, \(K_e \approx (10^{-1} \sim 10^{-2}) C_e\). Together with (32) it gives:

\[
(K_i)^{1/2} n < 5 \times 10^{20} [A/[C_e \tau_0^{1/2}]]^{1/2}, \text{ if } \tau_i < t_e, \quad (K_i)^{1/2} n < 5 \times 10^{24} [A/[C_e \tau_0^{1/2}]]^{1/2}, \text{ if } \tau_i > t_e.
\]

For \(A = 200, E_g = 10\) keV, \(\tau_i = 10^{-6}\) s, \(\lambda = 10^{-6}\) cm, \(\sigma_c = 10^{-18}\) sm\(^2\), \(K_e > 10^{-5}\) a gas-density is \(n < 10^{14}\) sm\(^{-3}\). Condition \(\sigma_c nL \approx 100\) (see ch.2) leads to \(L > 10^6\) cm, \(d = (\lambda L)^{1/2} \approx 0.1\) cm, \(N_e = n d^{1/2} L > 10^{18}\). It is difficult case. For SPTEN (see 2.1) the appropriate values are \(A = 58; E_g = 28.1\) keV; \(\tau_i = 1.51 \times 10^{-5}\) s; \(n = 10^{21}\) cm\(^{-3}\); \(n' = 1.76 \times 10^{27}\) cm\(^{-3}\); \(d = 3 \times 10^{-5}\) cm; \(n = 2 \times 10^{13}; \tau_{AM} \approx 10^{-12}\).

**Step 2.** Laser cooling\(^2\) uses rarefied non-ionized “almost ideal gas” when a force acting on any atom from cooling optical field (COF) is regular (non-chance) function \(F(r,V)\) of its velocity \(V\) and position \(r\). E.g., if \(V_i = V_j\). \(r = r_j\) for any \(i\) and \(j\) atoms, then in ideal gas \(F(r,V) = F(r,V_i)\). In case of ionized gas \((C_i > 0.001)\) the \(i\)-th and \(j\)-th atoms are differ owing to various charges or different Stark-effect in field of environment. So \(F(r_i,V) \neq F(r_i,V_j)\) and \(F(r,V)\) is a chance function. A moving for a majority of atoms at force \(R = -\nabla U(r) + F(r,V)\) is a long auto-oscillations different from fast damping in ideal gas. So laser cooling of a real gas-AM is strongly decelerated.

**Step 3.** The recoil force due to spontaneous emission of optical photon is about \(F_{sp} = 10^{-15}\) dynes and approximately equals to the chance force \(F_{ch} = |\delta U/\delta r|^\gamma|_0\) at \(n \sim 10^{14}\) cm\(^{-3}\); see step 1. It gives a hope of laser cooling, i.e., damping of axial velocity \(V_j < c/\tau_0 \sim 0.2\) cm/s with COF-power \(q' \sim 10^{14} M n V_e^2/(2\tau_0) \sim 10^{4} W/cm^2\) and flux \(P' \sim q' d \sim 10^{-5}\) W/cm\(^2\). Factor \(\sim 10^4\) accounts that energy transferred from gas to COF is small part of COF\(^2\).

**Step 4.** A heat release from internal conversion (HRFC) in case above is \(q \sim n E_e / \tau_0 \sim 10^{-5}\) W/cm\(^2\). HRFC is the main block in gas-AM because of its adiabatic isolation (cf. 3.1). For arbitrary \(n\) (in cm\(^{-3}\) L = \(10^{20}\) n\(^{-1}\) cm, \(d = 10^{-6}\) cm, \(n_e = 10^{25}\) n\(^{-1}\) cm, \(q = 10^{-10}\) W cm\(^3\), \(P = 10^{-9}\) W cm\(^2\)). If \(L = 10^6\) cm, then \(n = 10^{18}\) cm\(^3\), \(d = 10^{-3}\) cm, \(n_e = 10^{24}\), \(q = 10^{-9}\) W cm\(^2\), \(P = 10^{-3}\) W cm\(^2\), i.e., the cooling conditions are more hard than in solid.

**Step 5.** Gas-AM has an initial heat energy \(\sim 10^{-5}\) eV per atom (recoil-energy in nuclear reaction for ELAN-creation) or \(q_0 \sim (10^{14} - 10^{17}) J/cm^2\). This energy need be taken by COF for time \(\tau_0\). So additional flux of COF needs \(P = 10^{-10} Q d / \tau_0 \sim (1 - 10^{10}) 10^{-3}\) W cm\(^2\) \(\sim 10^{-5}\) W cm\(^2\). So steps 4-5 give a no go.

**Step 6.** In case of free nuclei beam: \(K_e = 1, \Delta \sigma = (10^{10} - 10^{12}) Z^2 \sim 10^{-6} - 10^{-4}\), where \(\sigma_0 = (e^2 Z^2/\alpha)^{1/2} \sim 10^{22} Z^2\) cm\(^2\) is Compton cross section for free nuclei, \(Z\) is number of protons in nucleus, \(\sigma_0 \sim (10^{22} - 10^{25})\) cm\(^2\) is usual cross-section of
non-resonant losses, see ch.1.2. Hence condition (33) is changed into $n < (10^{-4} - 10^{-5}) [A(\tau_1)Z_2E_2]^{32}$ with numerical results ($A \sim 200, Z \sim 100,$ see step 1): $n < (10^{-6} - 10^{-8}) \text{cm}^{-3}, L \sim 100/\sigma_n \sim 10^{-4} - 10^{-5} \text{cm}, d \sim (10^{-2} - 10^{-3}) \text{cm}, N_e \sim 10^{-16} - 10^{-14},$ it seems as eligible case. But it needs to account step 5: $J_0 \sim (10^4 - 10^5) \text{Wcm}^{-2}$ supposing that efficiency of COF is the same for both: atoms and free nuclei. But it is not so: efficiency for free nuclei is less by many orders. So a real $J_0 > 10^6 \text{Wcm}^{-2}.$ It's no go again.

**Step 7.** A dilution of free nuclei by free electrons $(Z \text{ per nucleus})$ changes factor $\zeta$ into $\zeta \sim Z\sigma \sigma_n - 1 - 10^{-2},$ where $\sigma_n$ is Thomson cross-section. Fast shielding by free electrons returns effective factor $\zeta > 10^{-3}$ with all rest results of step 1. Relativistic factor in $\zeta$ don't change sufficiently these results.

**Step 8.** Difficulties in steps 1–7 could be soften by use of MBE/MPE, which can decrease the values $C_v, q, Q_v, J_0$ by some orders.

**Step 9.** SPTEN is a hybrid of beam and solid g-lasers. In this hybrid the functions of gas-AIM are separated in space: the initial stage (creation of ELAN and high inversion) is sited in a beam; but the further functions (generation, cooling) are sited in solid. The results (theory, methodology, trial, technique) in elaboration of BGL independently on its practice could be useful for SPTEN.

### 5. PROGRAM-CONCEPTION FOR DEVELOPMENT AND CREATION OF GAMMA-LASER

The **Concept** as a single complete regarding ways for the experimental feasibility of $\gamma$-laser and a detailed program for the gamma-laser materialization are ready to experimental examination. Some topics of Concept are reflected in present work.

### 6. CONCLUSION

Model-SPTEN is feasible. For a long period (1980 – nowadays) it is steady to a plenty of difficulties. Such steadiness is based on main property of cold solids: quasi-particles (phonons, electrons, holes, but not atoms!) effectively provide the transferring of energy and charges. Another media have no such useful property. Many ways are revealed for experimental feasibility of $\gamma$-laser: devices for effective SPTEN-pumping on base of existing technique; modi to keep AM frozen during $\gamma$-lasing; effective nuclei-candidates with appropriate matrices; theory and handy formulas for analyses of real threshold conditions, heat and radiation regimes; analyses of further difficulties in gas and plasma AM: hot micro plasma in cold AM: conditions for the collapse of working heterogeneous spectrum into one narrow line; amplification without inversion (AWI) and schemes with inversion steady against micro plasma; $\lambda$-effect (with-path effect, WPE) on time $\tau_5;$ prospect of high powerful $\gamma$-lasers$^{8,9}$; usefulness of some results (MEB, DOCLM) in nowadays practice, etc. It needs a wide collaboration in these fields.

### 7. ACKNOWLEDGEMENTS


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