DISCHARGE IN INDIUM IODIDE VAPOR FOR LASER ON In 451.1 nm SELF-TERMINATING TRANSITION

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Pulse-periodical discharge in indium iodide vapor is proposed as a lasant for laser on In 451.1 nm self-terminating transition for the first time. The emission and absorbtion spectra of the discharge were studied in 220–500 nm spectral range. This system has a good chance to be useful to elaborate an effective laser in blue range of spectrum.

The history of lasers on self-terminating transitions (STT) oscillating from the upper resonant to the lower metastable level covers more than three decades. The number of obtained laser lines on STT in atomic and ionic spectra is not less than 44 (from ultraviolet 312.2 (Au) to infrared 6456.0 nm (Sr^+)). The parameters of these lasers are also impressive. A great number of unique properties (high range of pulse recurrence frequencies, high pulse and average lasing power, extremely high practical efficiency and gain of the active medium) being combined in the lasers of this kind have provided a constantly increasing wide area of their scientific, industrial and medical applications. During the first stage of intense development vast scientific research has been performed, being crowned by practically complete studies of main processes and physical phenomena in the active media of these lasers, lasing characteristics, techniques of obtaining metal vapors in discharge, being in most cases the active media of these lasers, elaborating of lasers with practical efficiency of ~ 1 % and average power of ~ 100 W and a great number of examples of applications of these lasers — mostly copper vapor laser (CVL).

However, even now the problem of the STT lasers has a number of "white spots". The key issue here, as for any scientific field, is: what comes next? We think that for the STT lasers the key issue lies in their broad practical applications. Creation of efficient blue STT laser is especially important; complementing a "good" copper laser in the green range and a "medium" gold laser in the red spectral range, may enable the creation of colour laser projecting systems and could also be useful for photochemistry, photolithography, for pumping dye lasers etc.

Among the blue STT lasers only bismuth [1] and iron [2] vapor lasers are known. However, they cannot be treated as "good" ones, because of very low average lasing power (mW), extremaly low efficiency and high operating temperature.

We have suggested the indium atom as a good candidate to search for laser action on STT in the blue spectral region that satisfies the well-known Gould criteria for efficient lasers. This paper presents the results of experimental investigation of the possibility of obtaining laser oscillation on the indium atom 451.1 nm STT.

The indium atom, that belongs to the third group of the periodical system of elements, is attractive due to its peculiar structure of energy levels (see Fig.1). The ground 5p $^2P_{1/2}$ and the metastable 5p $^2P_{3/2}$ (E_e = 0.274 eV) levels of In atom belong to the $4d^{10}5s^25p$ electron configuration. The 5p → 6s excitation of external electron results in the creation of an isolated resonant 6s $^2S_{1/2}$ state (E = 3.02 eV). The transitions between the levels of these configurations form a spectral doublet - the resonance 410.1 nm line and the STT 451.1 nm line. The boundary efficiency for this STT has a value of 60.6 %. An additional argument for the investigation of indium vapor as a promising active medium for the STT laser on blue line is that indium have the electron structure similar to that of the thallium atom, the laser generation on the STT of which was observed on the green line [3].

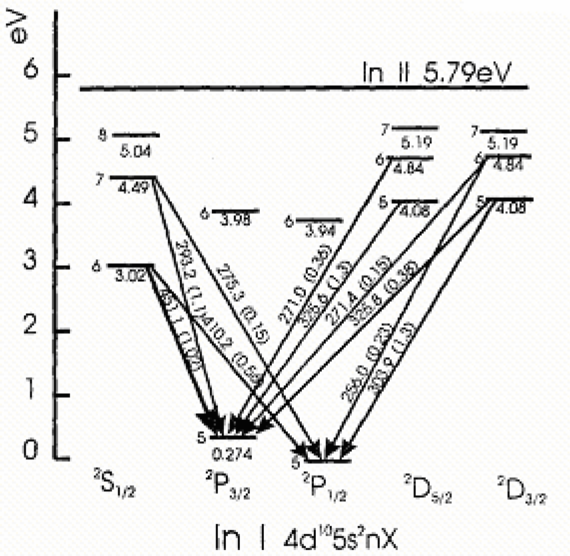

Fig.1. The structure of the indium atom energy levels (energy, eV) and transitions (wavelengths, nm; transition probabilities, $10^7\,s^{-1}$).

One should mention a number of limitations on the possibility of obtaining lasing on In STT line. First of all it is the very low energy of metastable level. The necessary saturated pressure of indium vapor (0.1 mm Hg) can be reached at 1042 °C [4] and under this condition the metastable to ground states population ratio has a value of 0.18. Meanwhile, one of the Gould criteria of effective STT laser as well as the experience of work with this lasers requires this ratio to be less than 10^{-3}. This excludes the possibility of using pure metal indium probe for vaporization in the active medium. Another limitation concerns the nonappropriate ratio between transition probabilities from the resonant level to ground and metastable states [5] (see Fig.1).

Experimental setup

In our investigations the discharge zone was confined by ceramic O-rings (10 mm ID) mounted in the quartz tube. The InI salt pieces were placed between them. The length of the discharge zone was 400 mm. An external oven was used for the discharge tube heating. According to [6], the saturated vapor pressure of InI 2 mm Hg (the smallest pressure at the scale) corresponds to 400 °C. The approximation of the pressure to 0.1 mm Hg gives the temperature value 300 °C. The discharge was excited in the pulse-periodical mode using the discharge circuit with a storage capacitor (2200 pF) and a commutational thyratron TGI1-2000/35. At the low frequency mode (up to 100 Hz) for the excitation of pulses in the discharge tube a power supply for nitrogen laser LGI-21 was used.

Experimental results

The discharge emission spectra (integrated by time) of the InI vapor mixture with neon and helium were investigated varying the excitation conditions (tube temperature 100 - 400 °C, buffer gas pressure 2–30 mm Hg, pulse repetition frequency 3–10 kHz and 100 Hz). To record these spectra the grating grid monochromator MDR-6, a photomultiplier FEU-106, an amplifier B7-30 and an X - Y recording device were used. An example of the obtained spectra is presented in Fig.2. These spectra are almost similar in spite of the different excitation conditions. In the whole range of the apparatus spectral sensivity the In atom spectral lines are dominant. The highest intensities are observed for the transitions from the resonant level and for the $5^2D_{3/2,5/2} \rightarrow 5^2P_{3/2}$ transitions (325.6 + 325.8 nm). Other atomic lines we determined as the transitions between the lowest states of the In atoms. Two molecular emission bands of the parent molecules InI - A → X (~ 410 nm) and B → X (~ 400 nm) [7] are also observed. A number of low intensity lines were not identified. Note that such kind of emission spectra is typical for the copper-halide STT laser.

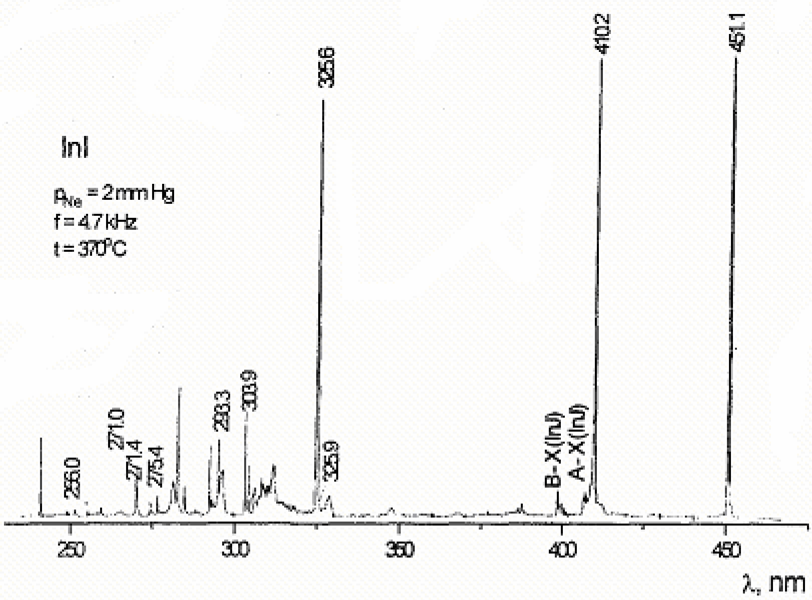

Fig. 2. The emission spectrum of the InI - Ne discharge

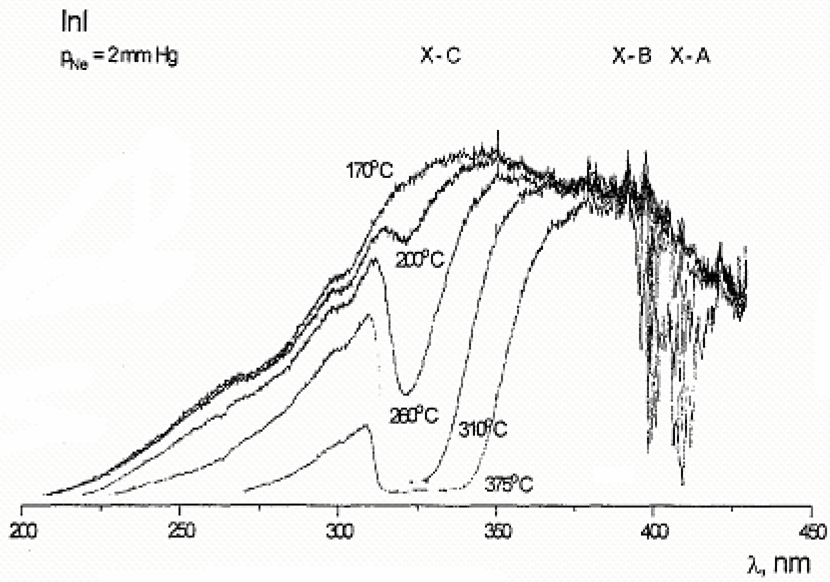

Fig. 3. The absorption spectrum of the InI - Ne vapor.

The absorption spectra were also obtained using the continuous spectral source (hydrogen and heating lamp), the radiation of which passed through the laser tube with the dicharge being switched off. The absorption molecular bands of InI X - A, X - B and X - C transitions were obsereved. The last one, C → X band was not detected in the emission spectra. The resonance 410.2 nm line of In lies within the X - A absorption band. At 400 °C the absorption in the tube is almost 100 %, nevertheless no considerable deflection from the usual intensity ratio of the 6s $^2S_{1/2}$ → 5p $^2P_{3/2+1/2}$ components was noticed. That is why the absorption of the plasma near the resonant line can not be qualified as a significant limitation for the lasing excitation, besides the amplification coefficient of the STT laser active media is usually much more larger than the observed absorption by few orders. At the pulse-periodical discharge mode with high pulse-repetation frequency this absorption is smaller because of the accumulative effects in the discharge tube of the dissociation products - indium and iodine atoms - and the decreasing of the InI molecules concentration. This is observed in the obtained emission spectra.

At the discharge mode with low frequency (100 Hz) the atomic indium transitions in the discharge plasma are emitted due to the process of the dissociative excitation of the InI molecules. The same excitation mechanism was realized in the STT thallium laser with the TlI salt as a source of the Tl atoms [3]. At the high frequency mode the process of the direct electron excitation of indium atoms is added. Moreover, during our investigations an another discharge mode was used - the mode of train pulses varying the repetition frequencies (1–20 Hz), the number of pulses in the train (5–20) and the time interval between the pulses in the train (50 – 500 μs). This mode is the best for varying the discharge parameters. Nevertheless, no stimulated emission was observed. We have suggested that the choice of the InI salt was not successfull, because of non-satisfactory ratio of the metastable to ground states concentration of indium atoms ~ 10^{-2} at the vapor pressure of 0.1 mm Hg. In future, the another chemical In compound will be used – $InBr_3$ – for which this ratio is $\sim 2\cdot 10^{-3}$.

References

1. S.V.Markova, G.G.Petrash, V.M.Cherezov, *Sov. J. Quant. Elect.* **4**, 1154 (1977).
2. M.J.Linevsky, T.W.Karras. *Appl. Phys. Lett.* **33**, 720 (1978).
3. A.A.Isaev, G.G.Petrash, *Pisma Zh. Eksp. Teor. Fiz.* 7, 204 (1968).
4. I.K.Kikoin. *Tables of Physical Constants* (Atomizdat. Moscow. 1976) [In Russian].
5. A.A.Radzig, B.M.Smirnov. *The Parameters of Atoms and Atomic Ions* (Energoatomizdat. Moscow. 1986) [In Russian].
6. *Chemical Hand-book. V1.* Ed. by B.P.Nicolsky (Khimiya. Leningrad, 1971) [In Russian].
7. K.P.Hubert, G.Herzberg. *The Constants of Diatomic Molecules* (Mir, Moscow, 1984) [In Russian].

РОЗРЯД У ПАРІ ЙОДИДУ ІНДІЮ ДЛЯ ЛАЗЕРА НА САМООБМЕЖЕНОМУ ПЕРЕХОДІ In 451.1 нм

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Уперше запропоновано активне середовище для лазера на самообмеженому переході 451.1 нм атома індію – імпульсно-періодичний розряд у парі йодиду індію. Вивчено спектри випромінювання розряду та поглинання у спектральному інтервалі 220–500 нм. Показано перспективність вказаної системи для створення ефективного лазера у синій області спектру.