Development and investigation of 2.39 μm-lasers for ecological monitoring

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A new approach to development of He–Ne lasers on cascade transitions with radiation wavelength 2.39 μm is considered. Mirrors of the resonator play the part of selective elements. The optimum parameters of laser generation on this transition are analyzed.

Рассматривается новый подход к разработке гелий-неоновых лазеров на каскадных переходах с длиной волны излучения 2,39 мкм. Роль селективных элементов играют зеркала резонатора. Рассматриваются оптимальные параметры генерации лазера.

The problem of environment ecological monitoring is closely connected with monitoring of fluorine containing substances. The real way for the problem solving is development and industrial production of gas analyzers based on He–Ne lasers operating at $\lambda = 2.3951$ μm that corresponds to the $3p_4$–$2s_2$ transition of neon. The transition mentioned is specific in that it is associated with inverse population of the laser levels $3p_4$ and $2s_2$. This transition belongs to so-called cascade laser transitions and is inverse in the case of laser action on the $3s_2$–$3p_4$ ($\lambda_1 = 3.39$ μm) transition (see Fig. 1) that populates the upper laser level $3p_4$ and laser action on the $2s_2$–$2p_4$ ($\lambda_2 = 1.15$ μm) transition that depopulates the lower laser level. Besides of the main transition from $3p_4$ level, the parasitic transition $3p_4$–$2s_4$ ($\lambda_{par1} = 2.035$ μm) takes place. Depopulation of the lower laser level of the parasitic transition occurs also due to stimulated emission $2s_4$–$2p_3$ ($\lambda_{par2} = 1.27$ μm). Presence of the parasitic laser transition $2p_4$–$2s_4$ results in decreased amplification coefficient of the main laser transition as well as decreased power of such laser as a whole. Laser emission of He–Ne medium on $\lambda = 2.3951$ μm was reported in [1]. Nevertheless, the optimum conditions of laser operation and resonator design peculiarities required for development of production prototype lasers are not studied.

The present work is aimed at development and investigation of He–Ne gas-discharge laser with high-selective resonator mirrors as dispersible elements. Basing on energy levels of neon, the mirrors of optical resonator must provide maximum quality factor of laser transitions at $\lambda_1 = 1.15$ μm and $\lambda_2 = 3.39$ μm; ultra low quality factor of laser transitions at $\lambda_{par1} = 2.035$ μm and $\lambda_{par2} = 1.27$ μm; and optimum spectral parameters at $\lambda_0 = 2.39$ μm. The totally reflecting mirror represents a quartz substrate with spherical working surface ($R = 1.5$ m) coated (by vacuum sputtering) with aluminum monolayer of about 1000 Å thickness. Such mirror provides reflection of about 98.5 % for the mentioned wavelength region that is sufficient for stimulation of all transitions from the cascade series.

In order to provide the output mirror, dispersion properties of interference dielectric coatings have been used. Application of numerical methods for synthesis of layer structures [2] allows to obtain thin-layer structures that satisfy the above-mentioned requirements most successfully. The output mirror so designed is a parallel-plane substrate internally coated with a thin-layer of

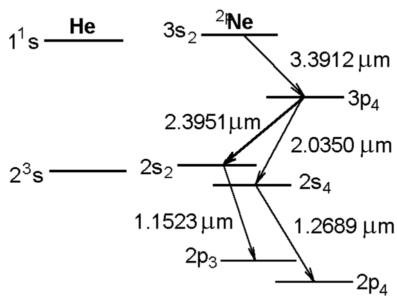

Fig. 1. Scheme of energy levels demonstrating the $3p_4$–$2s_2$ (λ_0 = 2.39 μm) cascade laser transition.

$$S_0(B,H)_3B, \quad \lambda = 2.39\mu m, \qquad (1)$$

and externally coated with a thin layer of

$$S_0(B,H)_3B, \quad \lambda = 3.39\mu m, \qquad (2)$$

where B and H represent quarter-wave layers for λ wavelength made from ZnS and Na_3AlF_6; S_0 is optical quartz substrate.

Fig. 2 represents reflection spectra of the both coatings of output mirror. Such composite mirror provides: (i) low (<10 %) reflectivity level of internal coating at wavelengths λ_1 = 1.15 μm and λ_2 = 3.39 μm; (ii) low (<10 %) reflectivity level of external coating at wavelength λ_0 = 2.39 μm; (iii) reflectivity of internal and external coatings at λ_{par1} = 2.035 μm <60 %; (iv) reflectivity of internal and external coverings at λ_{par2} = 1.27 μm <10 %. The conditions (i) and (ii) provide essentially complete separation of resonators for λ_1, λ_2 from λ_0, while conditions (iii) and (iv) prevent stimulation of parasitic transition at λ_{par1} = 2.035 μm.

The output mirrors prepared by vacuum sputtering were studied in open resonators with active elements having the gas-discharge space of 250 to 1000 mm length and 5 to 6 mm internal diameter. The charging system provides the discharge current from 10 to 60 mA. Maximum values of output power obtained for different active media are presented in Table. The studies were performed for 7:1 ratio of He:Ne partial pressures. The total pressure of mixture was 93 Pa. The laser output power was measured using an IMO-2M (USSR) instrument. In order to single out the main transition in laser output, a glass-germanium filter was used.

Dependences of output power on total pressure of He:Ne mixture obtained experimentally for different He:Ne ratios are presented in Fig. 3.

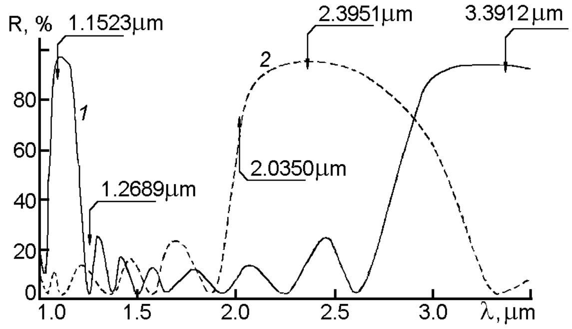

Fig. 2. Spectral dependences of reflectivity coefficient for thin-layer coatings of output mirror: external coating of structure (*2*) (*1*); internal of with structure (*1*) (*2*).

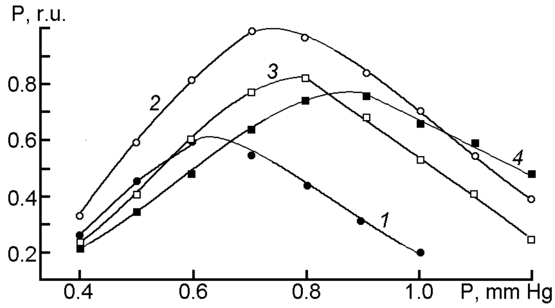

Fig. 3. Laser output power at λ_0 = 2.39 μm depending from total pressure of He:Ne active medium (l = 750 mm, d = 6 mm) at different He:Ne ratios: 6:1 (*1*); 7:1 (*2*); 9:1 (*3*); 10:1 (*4*).

It has been established that the optimum ratio of He:Ne partial pressures (P_{HE}/P_{NE}) lies in the range 6 to 11, while the total pressure of He:Ne mixture ensuring maximal linear and specific output power at λ_0 = 2.39 μm lies in the range 53 to 160 Pa. The optimum length to internal diameter ratio of gas-discharge space lies in the range 150 to 500. The optimum transmittance of output mirror at main transition wavelength is 4 to 12 %.

Table. Results of laser output at λ_0 = 2.39 μm obtained for various dimensions of active elements using the developed mirrors

No.	Length of gas-discharge space, mm	Diameter of gas-discharge space, mm	Output power, mW
1	250	5	0.3
2	400	5	0.6
3	750	6	1.2
4	1000	6	2.1

To conclude, the resonator design peculiarities as well as optimum conditions of laser operation obtained in the present work for He–Ne mixture at $\lambda_0 = 2.39$ μm can be rationally used to develop commercial models of such type lasers.

References

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Розвиток і дослідження 2.39 μm-лазерів для екологічного моніторингу

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Розглядається новий підхід до розробки гелій-неонових лазерів на каскадних переходах з довжиною хвилі випромінювання 2,39 мкм. Роль селективних елементів грають дзеркала резонатора. Розглядаються оптимальні параметри генерації лазера.