Reaction of lithium-6 with thermal neutrons as a source of nuclear-induced plasmas of gas mixtures

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The study of optical (laser and spontaneous) radiation of nuclear-excited plasma is of interest for the development of a method of energy output from a nuclear reactor, as well as for the control and regulating of nuclear reactor parameters [1]. Direct pumping of active media generally performed by nuclear reaction products such as $^{3}He(n,p)T$, $^{10}B(n,\alpha)^{7}Li$, $^{235}U(n,f)F$, or others using thermal neutrons from a nuclear reactor. The laser's active medium needs to include ^{235}U, ^{3}He, or ^{10}B, or a combination of these isotopes applied to the laser chamber's walls. The laser chamber's size and the nuclear reaction products' path length in the gas mixture define the degree of spatial inhomogeneity while utilizing a surface pump source. The use of lithium-6 as a surface source of excitation of the gas medium, due to the long path length of tritium nuclei in the gas (see Table 1), makes it possible to excite large volumes of gas in comparison with the use of uranium-235 or boron-10. Table 1 shows the path length for helium and argon gas, which most often serve as buffer gases in laser mixtures.

Isotope, isotopic distribution	Reaction cross section for thermal neutrons, barns	Products of reaction	Kinetic energy of reaction products, MeV	Path length of the products at pressure of 1 atm, cm [1]	
				He	Ar
^{10}B, 19.6%	3800	^{4}He	1.5	4.1	0.8
		^{7}Li	0.85	2.6	0.53
^{235}U, 0.72%	580	Light fission fragments	99	7.3	2.5
		Heavy fission fragments	68	6.2	2.2
^{6}Li, 7.5%	945	^{4}He	2.05	6.3 [*]	1.2 [*]
		^{3}H	2.73	35.0 [*]	6.7 [*]

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Table 1: Particle path length in helium and argon.

Studies of luminescence of gas mixtures under excitation by following nuclear reaction products:

$$^{6}Li + n \rightarrow {}^{4}He + {}^{3}H \quad (1)$$

were performed at the IVG.1M nuclear reactor with thermal neutron flux density up to $3 \cdot 10^{14}$ m/cm^{2}s. In the first experiments, lithium was applied by wetting liquid lithium with a layer thickness of about 50 μm on the surface of the chamber, and later capillary-porous structures (CPS) were used. The irradiation chamber was filled with the investigated gas mixture and loaded into the central experimental channel of the nuclear reactor. The emission spectra were recorded using a compact spectrometer QE65Pro (Ocean Optics). The results of studies of noble gas luminescence within a chamber with a lithium layer are given in [2, 3].

The present paper presents the results of investigations of the emission of argon-nitrogen mixture. The pressure at 300 K was 91 kPa for Ar and 2.4 kPa for N_2, and the thermal neutron flux density was $2.9 \cdot 10^{13}$ n/cm^{2}s. The lines of atomic argon and the bands of the second positive nitrogen system predominate in the spectra at 300-400 K. Upon increasing the temperature of the lithium layer up to ≈ 520 K, the lithium lines appear in the spectra, as well as the lines of sodium and potassium impurities (Figure 1).

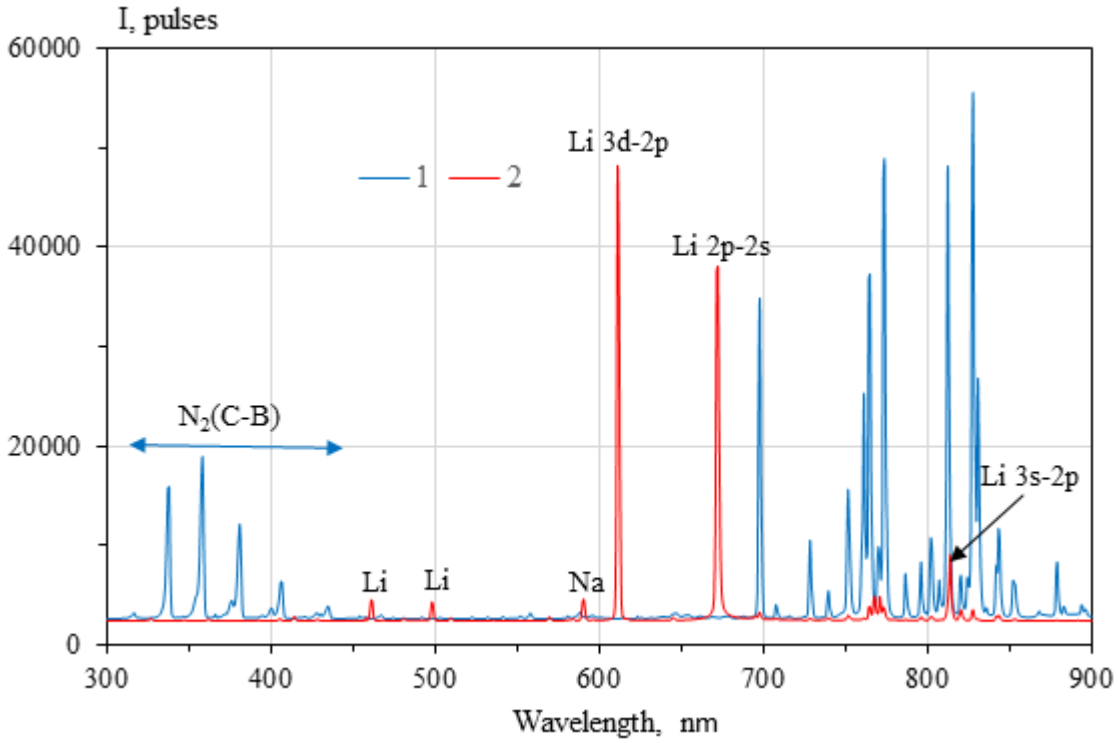

Fig. 1: Emission spectra of Ar-N_2 mixture at 375 K (1) and 720 K (2). The integration time of the spectrometer was 300 ms (1) and 10 ms (2).

The rapid increase in luminescence intensity at higher temperatures is well approximated by the following expression:

$$I \sim \exp(-{}^{A}/_{kT}) \tag{2}$$

where A - activation energy of this process. For the 610.4 nm lithium line, a value of A=1.68 eV was obtained. These values agree well with the lithium vaporization (sublimation) energy equal to 1.63 eV (156.9 kJ/mol) [4]). Since the saturated vapor pressure of lithium is low ($4 \cdot 10^{-6}$ Pa at 520 K and 0.08 Pa at 720 K), the emission process cannot be associated with the usual thermal evaporation of lithium. The lithium vapor density different from the saturated vapor density is formed in the gas excitation area by the nuclear reaction products.

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