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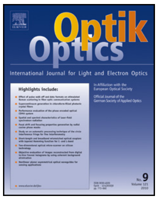

Original research article

Experimental and theoretical investigations for describing pressure dependence of amplified spontaneous emission output energy, small signal gain and electrical conductivity in nitrogen lasers

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ABSTRACT

An experimental arrangement consists of an oscillator amplifier (OSC-AMP) N_2 laser system having electrodes of different lengths, l_{AMP}, was used to measure the amplified spontaneous emission (ASE) output energy extracted from the AMP section at different gas pressure, p_{AMP}, and also the AMP small signal gain, g_0 at a constant p_{AMP}. It was observed that the extracted ASE output energy with respect to operational gas pressure has a non-symmetrical character. For explaining the observed behavior two different models for numerical calculations were applied for the results to be compared with each other and also with the experimental observations. The first model, i.e. the model of geometrically dependent gain coefficient (GDGC) was found to explain the pressure dependencies the observed behaviors of threshold and saturation lengths. The second model, which is based on using rate equations for N_2 lasers, coupled to the circuit electric discharge was used to calculate the pressure dependences of the ASE output energy and small signal gain. The results showed that ASE output energy versus gas pressure had a symmetrical behavior and within a limited range of gas pressure, small signal gain is a constant value. As geometrically the small signal gain and the electrical conductivity behave similarly, the model was also applied for predicting the pressure dependence of the electrical conductivity. Calculations of g_0 vs. l_{AMP} at $p_{AMP} = 90$ Torr based on applying both models are comparable with the measurements. It is concluded that the GDGC model can be suitably used for predictions of small signal gain, threshold and saturation lengths provided that ASE experimental measurements are available. The modified rate equations, on the other hand, can give appropriate results in absence of experimental measurements.

1. Introduction

Amplified spontaneous emission (ASE) for many years has been the subject of interest of researchers, both theoretically [1–12] and also experimentally, for example, in gas lasers [13,14]. Regardless of the fact that ASE is known as a drawback in high power lasers, due to depopulating the upper state of the active medium [15], it is also suggested to be used as a source

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of partially coherent radiation. In recent years in particular, the ASE has shown its potential for the study of polymer [16–20] or x-ray lasers [21–24].

The ASE is characterized by its broadband emission, when light is propagating along an inverted medium. For this reason reduction of the ASE in tunable lasers has been realized to be a challenging problem [25,26]. On the other hand, to determine gain coefficient in an inverted medium the variation of the ASE intensity with respect to variation of the medium excitation length was proposed initially by Shaklee and Leheny, where they introduced a simple equation for deducing small-signal-gain, g_0 [27]. The introduced equation was subsequently modified by Linford et al. [8]. Further modifications for the low and high gain saturation regimes and also for Lorentzian and Gaussian line shapes were accomplished by Svelto et al. [9]. In this case, for the equation to be applied, it is required to obtain the ASE output intensity or energy versus the length of the excited medium.

Experimentally in all the reported measurements on self-terminating gas lasers, polymers and x-ray lasers, it can be observed that the ASE in one-way propagation starts at some threshold length, Z_{th}. Thus, presence of Z_{th} in any ASE measurement is a clear indication that one is dealing with the ASE, provided that the output energy versus excitation length in a logarithmic scale initiates at Z_{th} increases rapidly and then reaches a saturated level. Although, in the earlier studies [1,2], the threshold length was introduced in their theoretical investigations, it was not further considered by the researchers in their theoretical investigations for analyzing the corresponding experimental data. In gas lasers Z_{th} for low pressure gas lasers with large excitation length are quite large. For example, in the earliest study for an active length of l_{AMP} = 200 cm and utilizing a back mirror, Z_{th} = 40 cm was reported [13]. For KrF laser, with l_{AMP} = 84 cm, it is ~20 cm [14]. For a low operational pressure of ~5 Torr in a longitudinally excited (LE) N_2-laser, no ASE emission in the amplifier (AMP) section of an oscillator-amplifier (OSC-AMP) system in all the applied amplification lengths of 15.5–35 cm was observed [28]. Other examples for N_2-lasers have shown that Z_{th} for high operational gas pressures also reaches high values. At 1.75 bar gas pressure, for example, it was shown that for a travelling wave corona excitation N_2-laser, Z_{th}~18 cm [29]. So far, this type of observation has not been theoretically investigated.

Another parameter that should be considered in the ASE study is the saturation length, denoted by Z_{sat}. This parameter although can be roughly estimated by observing the experimental plot of output energy ε^{ASE} vs. l_{AMP} in a logarithmic scale, but for its precise evaluation it is required to solve the ASE intensity or energy rate equation using the experimental measurements of ε^{ASE} vs. l_{AMP}.

Our past theoretical and experimental investigations have shown that there exists a great similarity on the ASE behavior in gas lasers [30], polymers [19,20], or even x-ray lasers [22–24]. Thus, further understanding of the ASE behavior on gas lasers can be utilized for analyzing other laser systems of our interests. For example, in our recent publication, we have shown that rate equations for a low pressure nitrogen laser can be used for predicting the time and space dependencies of the electrical conductivity, σ [31]. An important observation was also made to show that g_0 and σ with respect to l_{AMP} and kT_e, where k is Boltezman constant and T_e is the electron temperature, behave similarly. In this report, it was confirm that for understanding the behavior of the electrical conductivity, including the mechanism of runaway electrons in the discharge [32], one may consider dealing with the small signal gain and their relevant required rate equations, as well. In Ref. [33], also it is indicated the electrical conductivity, which is genereally considered as losses in laser theory, by considering the mathematical sign of σ, it can also considered as gain coefficient.

For the theoretical investigation usually rate equations are applied. In this work, however, two different methods of calculations, based on the model of geometrically dependent gain coefficient (GDGC model) and rate equations are used for the investigation of experimental observations of the ASE output energy, small signal gain and the electrical conductivity, and the results will be given to show the potential of each method to be used for explaining the relevant experimental observations when the laser operational gas pressure changes. Thus, this paper has been arranged firstly to present the behavior of Z_{th} and Z_{sat} with respect to gas pressure in an N_2-laser theoretically using the model of the geometrically dependent gain coefficient (GDGC). The requirement for performing the numerical calculation is to use experimental measurements of ε^{ASE} versus l_{AMP}. Such an experiment at a fixed low operational gas pressure of 20 Torr has been reported by Leonard [13]. As with a constant operational gas pressure, it was not possible to obtain the relevant functional dependencies of Z_{th} and Z_{sat} versus gas pressure, it was decided to carry out an experiment to obtain the ε^{ASE} vs. l_{AMP} profile experimentally. The laser which is required for this investigation should have variable excitation length, $l_{AMP,}$ and also capable to operate at different operational gas pressure, p_{AMP}. To explain experimental measurements of other researchers, for example, measurements that appeared in Ref. [13], the laser should be also able to operate at low gas pressure with no perionization. With this system, using the results of measurements and performing the numerical calculations, the relevant calculated profiles of the threshold and saturation length versus p_{AMP} were obtained. The profiles show that when the laser is operating at low gas pressure (for example, 20 Torr in Ref. [13]) we obtain large values for Z_{th} and Z_{sat}. These two quantities reduce considerably at a higher gas pressure of ~100 Torr. By further increasing p_{AMP}, the ASE calculation predicts that Z_{th} and Z_{sat} start increasing again. The pressure dependencies of Z_{th} and Z_{sat}, both at low and high operational gas pressure, although can be observed in a number of experimental reports such as those appeared in Refs. [13,29], for nitrogen lasers, however, so far no attempt has been made to explain their behavior theoretically. In fact, in most of research studies, the purpose of the studies have been focused on presenting their reports on the system operational parameters such as, output energy, laser efficiency, pulse width, etc., and the importance of such studies for further theoretical investigations have not been considered.

Secondly, to observe the potential of rate equations it is important to reproduce the ASE output energy ε^{ASE} with respect to operational gas pressure, p_{AMP}, theoretically. For this purpose, the modified rate equations are used. In this study, however,