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Optical noise reduction in a femtosecond Ti:sapphire laser pumped by a passively stabilized argon ion laser

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Abstract

Ionic gas lasers are widely used as optical pumps for a broad variety of solid-state and dye lasers. In such applications, the power fluctuations of the ionic gas lasers are contributing to the noise of the pumped lasers. In this paper, we report on the observation that a significant noise reduction can be achieved in a Ti:sapphire laser when it is pumped by a multiline argon ion laser stabilized with a passive external cavity. Under optimal conditions, the average optical noise of the argon ion laser beam was reduced by 20 dB over a spectral band ranging from 100 to 800 kHz. A similar noise reduction was observed in a Ti:sapphire laser when its pumping argon ion laser was stabilized with an external cavity; noise reduction occurred both in the continuous-wave regime and in the femtosecond regime. Our results are consistent with a model considering the response of the laser to pump fluctuations. We also compared the noise level of the Ti:sapphire laser when it was pumped by the stabilized argon ion laser to its noise level when it was pumped by an all-solid-state laser; our results indicate that, for frequencies above 125 kHz, the noise of the Ti:sapphire laser was significantly lower when the stabilized argon ion laser was used.

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1. Introduction

The optical intensity noise observed in ionic gas lasers originates either from mechanical, electrical or optical instabilities. The mechanical and electrical contributions to noise produce frequency components in the kilohertz range or below. Their effects can be alleviated with a careful mechanical design and an optimized electrical circuitry. Optical instabilities generate noise components at higher frequencies. It is most convenient to handle the noise components from

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optical origin by using passive optical methods. It has been shown that the reinjection of a few coherent photons in the cavity of mode-locked lasers having a short inversion lifetime can reduce significantly the laser intensity noise over a wide range of frequency components [1–15]. The technique has been termed coherent photon seeding (CPS). The noise reduction can be interpreted in the time domain by recognizing that, in the presence of CPS, mode-locked pulses build from the injected coherent photons rather than from incoherent photons produced by spontaneous emission [1,3]. It has also been shown that the reinjection of a small fraction of the output beam by a passive external cavity can reduce the optical intensity noise of continuous-wave (cw) lasers with a short inversion lifetime [16–19]. In cw lasers, the origin of noise reduction is rather understood in the spectral domain since coupled cavity effects lead to a drastic reduction of the number of oscillating longitudinal modes.

The method of coupled cavities can be easily implemented in most ionic gas lasers. Among ionic lasers, high-power argon ion lasers are the most widely used for the optical pumping of solid-state and dye lasers. Unless frequency selective elements are used, high-power argon ion lasers oscillate simultaneously on several emission lines and, for each wavelength, on many longitudinal modes due to inhomogeneous broadening of the gain medium. These modes interfere together and create a rich spectrum of beat notes at frequencies close to $nc/2L$, where n is an integer, c is the speed of light and L is the effective length of the laser cavity. For typical cavity lengths, these beat notes are observed at frequencies around 100 MHz and above. It should be emphasized that, due to the dispersion of the laser transitions, neighboring longitudinal modes are not separated by a constant frequency interval. As a result each beat note will actually be broadened by this effect. The numerous longitudinal modes also cause a significant low-frequency noise (below 1 MHz) through mode partition. These low-frequency noise components are generated through cross-phase modulation and cross-gain saturation due to the interactions of the sub-components of a given beat note with the gain medium [19].

Even though solid-state lasers have a much longer inversion lifetime than argon lasers and other ionic gas lasers, they are sensitive to such low-frequency noise components, particularly when there is an overlap of the noise components of the pump laser with the spectrum of relaxation oscillations of the solid-state laser. The reinjection of a few photons in the cavity of the ionic gas laser reduces the number of oscillating longitudinal modes through the spectral selectivity of coupled cavities; this process leads to the simultaneous reduction of the corresponding beat notes and of the associated low-frequency noise components. One would then expect a similar noise reduction in the emission of a solid-state laser pumped by an ionic gas laser stabilized with a passive external cavity.

In this paper, we report on our experimental observation of the noise reduction in a femtosecond Ti:sapphire laser optically pumped by a passively stabilized argon ion laser. The paper is divided as follows. First we describe in Section 2 the experimental setup where a multiline argon ion laser was operated with an external cavity ended by a semitransparent mirror. That design was used to optimize the output power while maintaining a significant noise reduction. Section 3 follows with the presentation of the results on noise reduction in the argon ion laser. The experimental measurements of noise reduction in the Ti:sapphire laser are reported in Section 4, both in the femtosecond and cw regimes. The noise of the Ti:sapphire laser was studied with two different pump lasers: an argon ion laser (free-running or stabilized with an external cavity) and an all-solid-state green laser source. The observed noise reduction is compared to the predictions of a model describing the response of the Ti:sapphire laser to pump fluctuations. A discussion of the results is presented in Section 5.

2. Experimental setup for the passive stabilization of the argon ion laser

The reduction of the optical intensity noise of a multiline argon ion laser (Coherent Inc., model Innova 310) has been done with the setup shown