

Ultra-photo-stable coherent random laser based on liquid waveguide gain channels doped with boehmite nanosheets

Hua Zhang^{a,*}, Hong Zhang^{a,*}, Chao Yang^a, Jiangyun Dai^a, Jiajia Yin^a, Hongyan Xue^a, Guoying Feng^{a,*}, Shouhuan Zhou^{a,b}

^a Institute of Laser and Micro/Nano Engineering, College of Electronics and Information Engineering, Sichuan University, Chengdu, Sichuan, 610064, China

^b North China Research Institute of Electro-Optics, Beijing, 100015, China

ARTICLE INFO

Article history:

Received 8 August 2017

Received in revised form 3 December 2017

Accepted 5 December 2017

Available online 8 December 2017

Keywords:

Coherent random laser

Liquid waveguide gain channels

Boehmite nanosheets

Multiple scattering

Closed-loop cavity

ABSTRACT

Construction of ultra-photo-stable coherent random laser based on liquid waveguide gain channels doped with boehmite nanosheets has been demonstrated. An Al plate uniformly coated with boehmite nanosheets was prepared by an alkali-treatment method and used as a scattering surface for the coherent random laser. Microcavity may be formed between these boehmite nanosheets owing to the strong optical feedback induced by the multiple light scattering. Many sharp peaks are observed in the emission spectra, and their laser thresholds are different, which confirms the feedback mechanism is coherent. The linewidth of the main peak at 571.74 nm is 0.28 nm, and the threshold of the main peak is about 4.96 mJ/cm². Due to the fluidity of liquid waveguide gain medium, the photostability of this coherent random laser is better than the conventional solid state dye random lasers. The emission direction is well constrained by the waveguide effect within a certain angular range ($\pm 30^\circ$). This kind of coherent random laser can be applied in optical fluid lasers and photonic devices.

© 2017 Published by Elsevier B.V.

1. Introduction

Over the past two decades, the random laser has been widely studied both theoretically and experimentally. Compared with conventional lasers, random laser owns many unique characteristics, for example, three-dimensional laser emission [1], multimode emission and low spatial coherence [2]. The random laser has potential applications in full field imaging and projection [3], cancer diagnosis [4], pH sensing [5], substance detecting [6,7], information retrieval [8] and so on. According to the different feedback mechanism, random laser can be divided into two categories: non-coherent random laser and coherent random laser [9]. For the non-coherent random laser, light propagation is diffusive, which means that interference has negligible contribution to the optical feedback, and the non-coherent random laser emission spectrum only shows a broad single peak within a few nanometers [10,11]. While for the coherent random laser, the photon transport mean free path is in the same order of magnitude as the emission wavelength, so Anderson localization of light may occur, i.e. photons may

propagate along a closed loop path which acts as a microcavity [12]. Random lasers have been obtained in a large number of disordered media, such as semiconductor powders [13–15], dye solutions doped with scattering particles [16], liquid crystals doped with laser dye [17–21], random fiber lasers [22,23], biological tissues impregnated with fluorescent molecules [24], etc.

Optofluidic dye laser is a class of liquid dye laser, usually constructed by microfabrication technology, has potential application in on-chip laser [25–27]. Due to the fluidity of liquid gain medium, optofluidic dye lasers can effectively avoid photodegradation of organic dye. In 2006, Song et al. reported unidirectional narrow linewidth lasing from a planar random microcavity laser which combines a planar microcavity and a random laser [19]. Lin et al. obtained random laser emission from dye doped polymer dispersed liquid crystals [28] and dye doped liquid crystals [20] in a capillary. These random lasers combine random laser medium and external microcavity or waveguide structure. Random laser based on liquid waveguide gain channels is a combination of random laser, waveguide structure and optofluidic laser, thus leading to many advantages, such as good photostability, easy manufacture, and low cost. In 2014, Zhang et al. demonstrated a coherent random laser based on liquid waveguide gain channels with the micro/nanostructures of butterfly wing [9]. Additionally, they also reported a coherent random laser based on a sandwich structure

* Corresponding authors.

E-mail addresses: zh.qy@scu.edu.cn (H. Zhang), guoying_feng@scu.edu.cn (G. Feng).

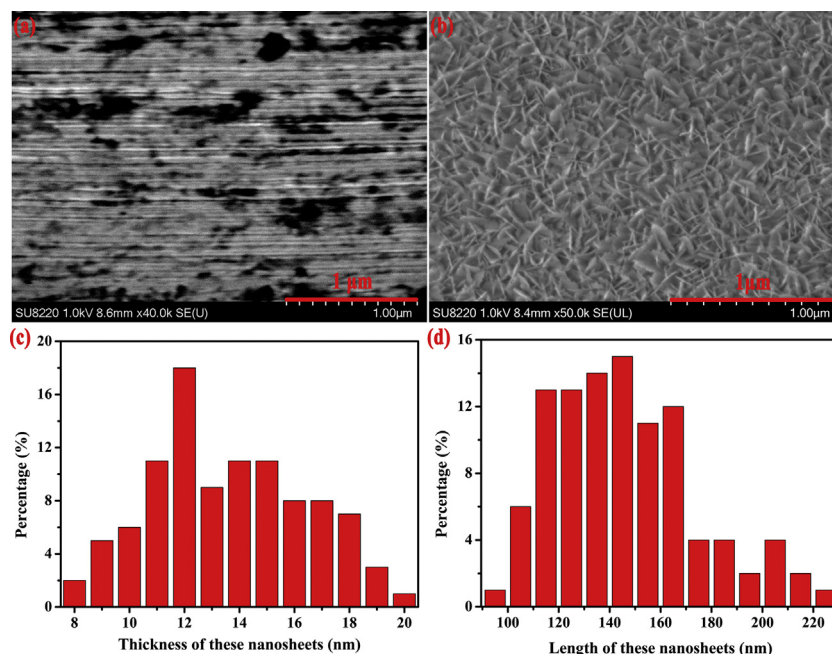


Fig. 1. Typical scanning electron micrograph (SEM) images of (a) pure Al plate and (b) 1 min alkali-treated Al plate. The distribution of the thickness and length of these nanosheets.

which consists of two MgF_2 plates and a liquid gain medium doped with Ag nanoparticles [29]. Similarly, Cui et al. fabricated a coherent random laser based on the same sandwich structure, but the two MgF_2 plates and Ag nanoparticles were replaced by two polydimethylsiloxane plates and silica nanoparticles [30].

In our work, coherent random laser based on an alkali-treated Al plate acting as the scattering surface has been constructed. This coherent random laser device owns a sandwich structure, which consists of a thin Rh6G ethanediol solution gain layer, an MgF_2 plate, and an alkali-treated Al plate covered with uniformly distributed boehmite nanosheets, as shown in the inset of Fig. 2. Multiple light scattering caused by boehmite nanosheets provides optical feedback to our experimental device. Many sharp coherent random laser emission peaks were achieved in our device. Due to the waveguide effect, the direction of laser emission is limited in a narrow range of angle. Photostability of our set-up is better than that of solid-state dye random lasers [31,32].

2. Experimental setup and principle of measurement

The preparation of alkali-treated Al plate was developed from the references [33,34]. Firstly, Al plate ($30\text{ mm} \times 40\text{ mm} \times 1\text{ mm}$) purchased from Sinopharm Chemical Reagent Co., Ltd was ultrasonically cleaned by acetone, ethanol and deionized water successively for about 15 min, as shown in Fig. 1(a). Secondly, the cleaned-Al plate was alkali-treated by 0.05 M NaOH solution at 80°C for 1 min. At last, the alkali-treated Al-plate was immediately immersed in the boiling deionized water for 30 min to stabilize these nanosheets. Fig. 1(b) depicts that these nanosheets are uniformly distributed on the surface of Al plate. As shown in Fig. 1(c) and (d), the average thickness and length of these nanosheets are around 14 nm and 19146 nm, respectively. Some nanopores are formed by these nanosheets. Fig. 2(a) shows the high-resolution O 1s line, which can be deconvoluted into three peaks, H_2O , OH and O, corresponding to 533.0 eV, 531.8 eV and 530.5 eV, respectively. In Fig. 2(b), Al 2p binding energy peak is at 73.9 eV. These results coincide with that of boehmite reported in the literature [35]. Additionally, the alkali-treated Al plate was characterized by the energy

dispersive X-ray spectrometry (EDS), which was operated at 6.0 kV. As shown in Fig. 2(c), the atomic ratio of O (64.33%) to Al (35.67%) is about 2:1, which correlates with that of boehmite. Therefore, from the XPS and EDS characterization and analysis, these nanosheets should be boehmite.

In these experiments, the coherent random laser device with a sandwich structure is utilized, which mainly consists of a $6\text{ mm} \times 5\text{ mm} \times 1\text{ mm}$ MgF_2 plate, a thin Rh6G ethanediol solution ($2 \times 10^{-3}\text{ M}$) gain layer, and an Al plate covered with boehmite nanosheets. The refractive index of MgF_2 ($n_1 = 1.38$) is lower than that of the Rh6G ethanediol solution ($n_2 = 1.43$). However, the refractive index of boehmite ($n_3 = 1.65$) is higher than the ethanediol. Consequently, liquid waveguide gain channels doped with boehmite nanosheets have been formed.

Fig. 3 illustrates the schematic of the experimental set-up for optical measurement. The sample was optically pumped by a second harmonic Nd:YAG laser (ZYLASER, penny-25). The pump wavelength is 532 nm, at which the absorption of Rh6G molecules is relatively strong. The pulse duration and repetition rate of the pump laser is 9.3 ns and 10 Hz. The pump laser intensity was measured by an energy meter (Ophir PE9F-SH). The laser was focused on the liquid gain layer through a cylindrical lens to form a stripe ($1\text{ mm} \times 10\text{ mm}$). A multimode fiber coupled with the AvaSpec-USB2/3 ($\sim 0.07\text{ nm}$ resolution) was introduced to measure the emission spectra. In addition, the pump intensity was limited below the damage threshold of Rh6G molecules to avoid photobleaching [32].

3. Results and discussion

Fig. 4(a) illustrates the emission spectra of the reference sample based on un-alkali-treated Al plate. Owing to the confinement effect of the waveguide structure, the emission spectrum displays a typical amplified spontaneous emission (ASE). Different from the reference sample, due to the existence of boehmite nanosheets, intensive multiple light scattering occurs at the interface between alkali-treated Al plate and liquid gain layer, which provides enough optical feedback for coherent random laser emission. As illustrated

Download English Version:

<https://daneshyari.com/en/article/7932809>

Download Persian Version:

<https://daneshyari.com/article/7932809>

[Daneshyari.com](https://daneshyari.com)