

A HIGH Q-FACTOR, EASY-TO-USE, BROADBAND Ce:LiCAF LASER RESONATOR BASED ON TOTAL INTERNAL REFLECTION

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Received 29 November 2016

Accepted for publication 05 January 2017

Abstract. *We report a design of a cerium-doped lithium calcium hexafluoro aluminate (Ce:LiCaAlF₆, Ce:LiCAF) laser resonator based on total internal reflection (TIR). This TIR configuration is established by placing the Ce:LiCAF crystal between two calcium fluoride (CaF₂) Pellin-Broca prisms. The laser resonator exhibits a 289-nm emission with 3.5-nm spectral linewidth and 4.4-ns pulse duration. Results show that the present configuration can be a high Q-factor, easy-to-use, broadband prism resonator suitable as a laser oscillator not only in the ultraviolet (UV) region but also down to vacuum ultraviolet (VUV) wavelengths where alignment is restricted to vacuum environments.*

Keywords: laser resonator, total internal reflection, fluorides, VUV.

Classification numbers: 42.60.Da, 42.60.-v.

10 Hz repetition pulse rate was used as an excitation source. The laser beam was focused on the Ce:LiCAF crystal by a 70 cm focal-length lens to create a 5 mm diameter spot, that means the pump spot overlaps the entire length of the laser crystal. The Czochralski method-grown crystal has $5.0 \times 5.0 \times 10$ mm dimensions and has polished surfaces. Two CaF_2 Pellin-Broca prisms were used to establish TIR on the side-pumped laser resonator. The Ce:LiCAF crystal was placed between the PB prisms at an angle of 11° with respect to the oscillation axis. The CaF_2 prisms were aligned with respect to the crystal so that the incident angle was around the Brewster angle at 289 nm. One of the PB prisms (left prism in Fig. 1) was rotated by a few degrees to allow a part of the 290 nm laser emission to escape the resonator. The slope efficiency, spectral profile and pulse duration of the laser emission were evaluated.

III. RESULTS AND DISCUSSIONS

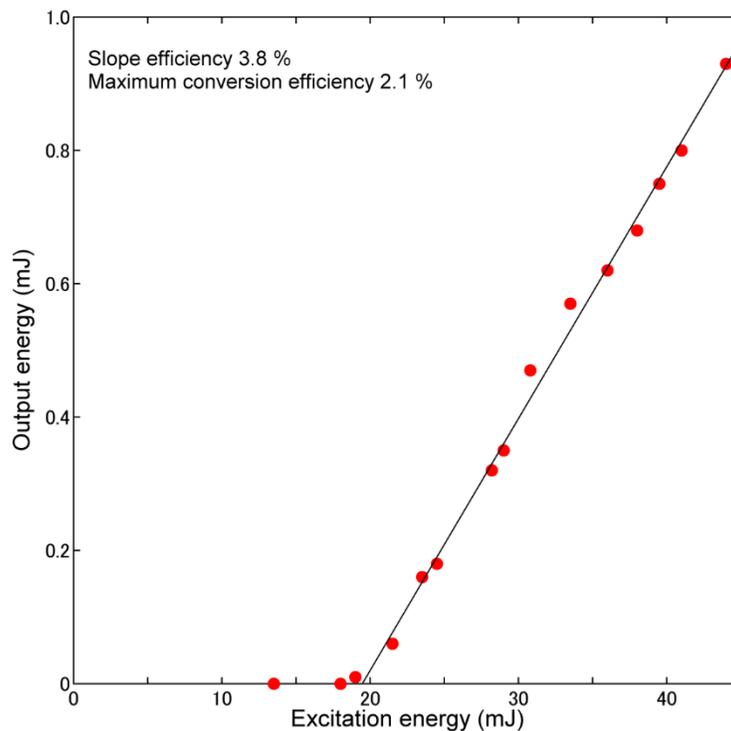


Fig. 2. Output energy of the Ce:LiCAF laser resonator as a function of the Nd:YAG excitation energy. The slope efficiency is around 3.8%, and maximum conversion efficiency is around 2.1%.

Figure 2 shows the output energy of the Ce:LiCAF laser resonator as a function of the Nd:YAG excitation energy. The slope efficiency is estimated to be around 3.8%, and the maximum conversion efficiency is around 2.1%. The obtained efficiency of the present prism resonator is lower compared to previous reports. A 46% conversion efficiency has been obtained from Ce:LiCAF using an output coupler with 60% reflectance [9]. The lower efficiency can be attributed

to the low reflectance of the crystal's side surface. Assuming that the refractive index (n) of Ce:LiCAF is the same to that of undoped LiCaAlF₆ (1.404) [10], the reflectance will be only 2.7%. The typical absorption coefficient of Ce:LiCAF at the emission wavelength (290 nm) is 0.2 cm^{-1} and its absorption coefficient at the pump wavelength (266 nm) is 3.2 cm^{-1} [11]. Therefore, the figure of merit of our oscillator setup is about 16. The figure of merit was calculated as the ratio of the absorption coefficient of Ce:LiCAF at the pump and emission wavelengths ($3.2 \text{ cm}^{-1}/0.2 \text{ cm}^{-1}$). The two CaF₂ Pellin-Broca prisms are highly transparent at 290 nm, hence its absorption coefficient at the lasing wavelength (290 nm) is close to zero. Nevertheless, our results demonstrate the design of a laser oscillator based on TIR using two PB prisms. This design will be even more important for VUV lasing where the set-up needs to be in vacuum. Figure 3 (a) and 3(b) show the spectral and temporal profiles of the Ce:LiCAF laser emission. The laser emission peak is centered at 289 nm, and its spectral linewidth is $\sim 3.5 \text{ nm}$. Compared with the 7.6 ns pulse duration of the pump beam, the laser pulse duration of the PB prisms laser is only 4.4 ns. These results demonstrate that Ce:LiCAF laser emission can be achieved using the present laser resonator.

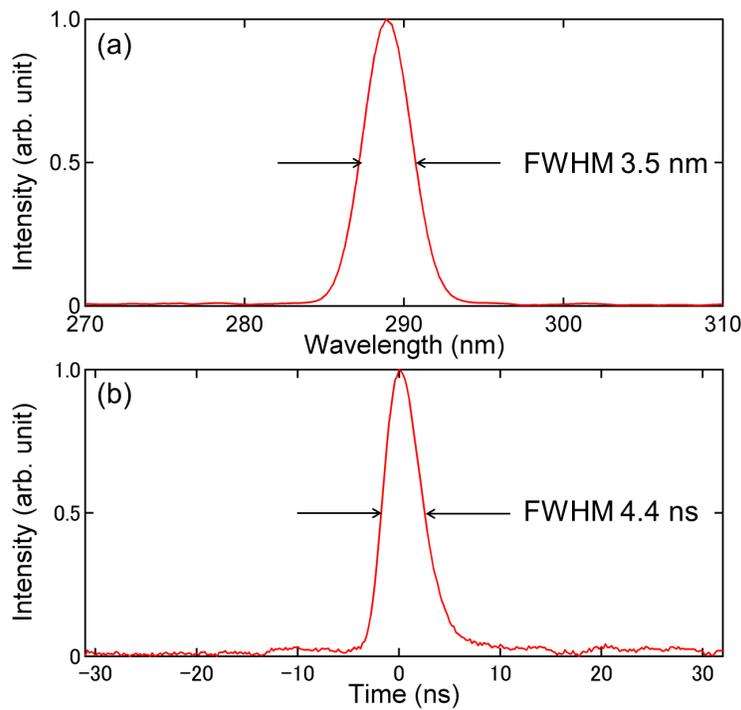


Fig. 3. (a) Spectral profile and (b) temporal profile of the Ce:LiCAF laser resonator emission. The laser resonator has a peak wavelength at 289 nm with 3.5-nm spectral linewidth and a pulse duration of 4.4 ns.

Laser oscillation can be achieved by TIR using two Pellin-Broca prisms. The PB prisms were used to achieve Brewster angle incidence at the prism surfaces and, therefore, minimize reflection losses of 290-nm laser emission. Moreover, typical laser oscillators consist of dielectric

multilayer mirrors whose reflectance greatly depends on the incident wavelength. Our results show that alignment of the Pellin-Broca resonator can be varied for different laser media due to the low reflection loss of p-polarized light at angles away from the Brewster angle of the prism. For example, a 2° difference between the incidence and the Brewster angles causes less than 0.1% reflection loss [12]. This means that a high Q-factor resonator can be maintained with even a rough alignment of the prisms. Maintaining a high Q-factor resonator is suitable for evaluating whether the candidate laser medium can oscillate or not. Moreover, a 90° -angle prism makes the alignment of the resonator easy because the number of rotation axes, which require precise adjustment of the prisms, is decreased by one. The use of Brewster incidence of the prism also reduces the risk of optical damage compared to using antireflection coating at normal incidence. CaF_2 is transparent causes very minimal loss in the VUV region. For instance, internal absorption loss of a 10 mm thick Nikon CaF_2 lens at 157-nm wavelength is less than 0.5% [13]. For these reasons, the CaF_2 Pellin-Broca prism resonator that we have designed can be a high Q-factor, easy-to-use, broadband laser resonator suitable as a laser oscillator in different wavelength regions not only in UV but also down to VUV.

IV. CONCLUSION

We designed a Ce:LiCaAF laser resonator based on TIR established by using two CaF_2 Pellin-Broca prisms. Laser emission from the Ce:LiCAF crystal was observed at around 289 nm. Our results suggest that this prism resonator can potentially be used in the VUV region where alignment of a resonator is limited by vacuum conditions. Further investigations are anticipated in the future to demonstrate VUV lasing with this resonator using other fluoride crystals such as Nd:LiCAF, Nd:LaF₃, Nd:LaBaF or Nd:LuLiF.

V. ACKNOWLEDGMENTS

This work was supported by the Vietnam National Foundation for Science and Technology Development (NAFOSTED) under Grant Number 103.03-2015.29.

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