1. INTRODUCTION

Coherent continuous-wave light sources in the visible spectral range have become interesting for many technical applications in medicine, lithography, communications, display, and other areas. In particular, diode-pumped solid-state laser systems have been established as an efficient and compact light source for these applications. Nd\textsuperscript{3+} doped crystals are suitable for such sources because of the high gain and good thermal and mechanical properties they provide. Commonly, the \(4F_{3/2} \rightarrow 4I_{11/2}\) and \(4F_{3/2} \rightarrow 4I_{13/2}\) transitions are used, corresponding to radiations around 1.06 and 1.3 \(\mu m\), respectively. Red, green, or yellow radiations can then be obtained by frequency conversion, leading to simple and compact lasers emitting in the visible range [1–30]. New solid state lasers were designed to enlarge the panel of wavelengths, for example in the yellow range [31–34]. One way is sum-frequency mixing between two transitions of the neodymium ion in the same laser medium. Because of strong gain competition between these two laser lines, dual wavelength operation in a single laser crystal is inefficient [31, 32]. Another way is to use two crystals in two different cavities sharing a common part for intracavity sum-frequency mixing. However, two pump focus points are needed (one for each crystal) for efficient laser action under diode pumping. This leads to an increase of the complexity of the pumping setup [33, 34].

In this paper, we present a more simple architecture where the diode is pumping only the first Nd:YAG crystal used as laser medium at 946 nm, and the second Nd:YAG laser emitting at 1319 nm intracavity pumped at 946 nm. Sum frequency mixing between the two laser lines is realized in the common part of the two cavities in a LBO crystal to reach the cyan laser at 551 nm.

2. EXPERIMENTAL SETUP

The principle of the cascade pumping is described in Fig. 1. The diode laser at 809 nm pumps the first Nd:YAG crystal used as the laser medium at 946 nm, and the emission of 946nm pumps the other Nd:YAG to generate 1319 nm transition. Pumping a Nd:YAG crystal at 946 nm is possible because the lower level of this \(4F_{3/2} \rightarrow 4I_{9/2}\) transition is thermally populated. Even if the absorption coefficient (0.076 cm\(^{-1}\)) is rather low (Fig. 2), it can be enhanced if the crystal is put inside the cavity operating at 946 nm to take benefit from the high intracavity power.

The experimental setup is shown in Fig. 3. The pump source of the 946 nm laser was a fiber-coupled diode at 809 nm with a core diameter of 400 \(\mu m\) and a numerical aperture of 0.22, and provided a maximal power of 20 W. An optical system made of two achromatic lenses was employed in order to image the fiber end into the first Nd:YAG crystal. The waist of pump beams was measured to have a radius of nearly 210 \(\mu m\).

The first Nd:YAG crystal was 1.0% doped and \(\square 4 \times 3 \text{ mm}\) size. The second Nd:YAG crystal was 1.0% doped and \(\square 4 \text{ mm} \times 5 \text{ mm}\) size. Both gain medium faces were antireflection (AR) coated at 946 and 1319 nm. Both laser crystals were wrapped with indium foil, mounted in a copper holder and cooled through the resonator base plate, which is kept at a constant temperature of 15°C by a thermo-electric cooler favorable to yield a small thermal population of the terminal laser level and the stability of the output power. Three mirrors composed the cavity operating at 946 nm (M1, M3, and M4). M1 and M3 were coated for high reflection (HR) at 946 nm and AR at 1319 nm to prevent any gain competition in the first Nd:YAG crystal. The output mirror M4 was coated for HR at 946 and 1319 nm and AR at 551 nm and 1064 nm. The 1319 nm cavity consisted of two mirrors, M2 and M4.
were coated for HR at 1319 nm and AR at 1064 nm. Two plano-concave mirrors (M1 and M2) with the same radius of curvature of 500 mm were chosen. A LBO crystal cut for type-I critical phase matching in the principal plane $XY$ ($\theta = 90^\circ$, $\varphi = 8.4^\circ$ with $d_{\text{eff}} = 0.836 \text{ pm/V}$) was chosen as the nonlinear crystal due to its high anti-damage threshold (18 GW/cm$^2$) and much smaller walk-off angle (about 9.17 mrad). The size of the LBO crystal is $2 \times 2 \times 10 \text{ mm}^3$ and both end faces were coated with AR film at 946, 1319, and 551 nm wavelengths. It was wrapped with a thin indium foil and mounted in a copper holder, which was cooled by a thermoelectric cooler for an active temperature control. The cavity length was 60 mm for 946 nm oscillation and the cavity length was 52 mm for 1319 nm oscillation.

3. RESULTS AND DISCUSSIONS

In the second waist of the cavity (cavity at 1319 nm), we introduced the second Nd:YAG crystal. We investigated laser performances with different Nd:YAG crystal length. The different efficiency curves are presented in Fig. 4.

**Fig. 1.** Principle of the cascade pumping.

**Fig. 2.** Room-temperature absorption spectrum of 1.0 at % Nd-doped Nd:YAG crystal.

**Fig. 3.** Schematic diagram of the experimental setup.