100 W CW CLADDING-PUMPED RAMAN FIBER LASER AT 1120 NM.

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In recent years, rare-earth doped silica fiber lasers have become a popular medium to generate very high-power laser source, in particular in the 1 µm range where up to 10 kW single-mode ytterbium-doped fiber (YDF) laser source has been reported [1] and up to 0.9 kW from Tm doped fiber [2]. The powers from other wavelengths are much lower typically between 10 to 100 W. An alternative to produce gain and power in optical fiber is to use nonlinear effect such as stimulated Raman scattering (SRS). SRS is wavelength agile, limited only by the transparency range of the fiber and the pump power wavelength. In addition, SRS sources benefit from low quantum defect, in particular at shorter wavelengths making them extremely efficient. However, because these effects rely on strong optical intensities to take place, fibers with small core size are typically used with core pumping scheme, limiting the scope for power scaling. Therefore, no very high power Raman fiber laser (RFL) has been reported and little progress has been made to increase the output power of those. As far as we are aware, the highest reported power from a core-pumped RFL is about 68 W from [3]. There are several challenges in power scaling core-pumped Raman fiber laser, mainly the power handling capacity of single-mode fiber and the careful adjustment of the fiber length to avoid spurious 2nd order Stokes generation in the laser cavity.

In the past, we have proposed [4] a radically different approach for Raman fiber laser sources based on cladding pumping of well designed double-clad fiber [5]. Here, a low-brightness pump which is propagating in a passive double-clad fiber is converted through SRS into the diffraction-limited core mode at the Stokes wavelength. This is similar to the operation of rare-earth doped fiber. Previously, we reported a 10 W single-moded output cladding-pumped Raman fiber laser at 1660 nm [6]. Here, for the first time we present a high power cladding-pumped Raman fiber laser at 1120 nm with 100 W of output power.

Our set-up consists of a pump laser source and a Raman fiber laser. Figure 1 shows the set-up and the configuration of the Raman laser. The Raman pump laser is an ytterbium-doped fiber amplifier at 1064 nm delivering over 150 W of pump power with a multimode output beam with a $M^2 \sim 2$. The pump light is launched into a free-space high-power isolator to isolate the YDF from any reflections originating in the Raman laser. The Raman fiber laser consists of an 85 m long germanium-doped double-clad Raman fiber (DCRF) in a linear cavity. The DCRF was manufactured in-house by using a standard modified chemical-vapor deposition process. The fiber has a pure silica outer cladding. The inner cladding and core consist of germanosilicate with different germanium contents to enhance the Raman process and to define the desired waveguide structure. The diameter of the inner cladding is 21.6 µm, and its NA is 0.22 with respect to the outer cladding. The core diameter is 9 µm, and its NA is 0.14 with respect to the inner cladding so the fiber core is well multimoded at 1120 nm. The pump light is launched through a flat-cleaved end face of the Raman fiber. This forms the output coupler of the Raman laser cavity, using the 4% Fresnel reflection. The pump through that is not converted into Stokes power is removed by a dichroic mirror (M2) after the length of fiber. Furthermore, we added an additional mirror (M3) to remove any 2nd order Stokes light from the laser cavity. Finally, a highly reflective (HR) mirror at the lasing wavelength completes the laser cavity. The laser light exits through a mirror (M1) that separates the pump and Stokes wavelength.

The laser output power and pump throughput are showed in figure 2. For 160 W of launched pump power, we obtained 100 W at the lasing wavelength of 1120 nm. We believe this is the highest power reported from any Raman fiber laser. The laser slope efficiency is 71% with respect to launched pump power. This is comparable to typical ytterbium fiber laser. Considering the pump through that is not converted we obtain a slope efficiency of 80% which is lower than the quantum defect. We attribute that to various losses in the HR end of the laser cavity. This is confirmed by operating the same fiber in a 4% - 4% laser cavity to 100 W with an efficiency of 84% vs. launched pump power and 91% w.r.t. absorbed pump power.

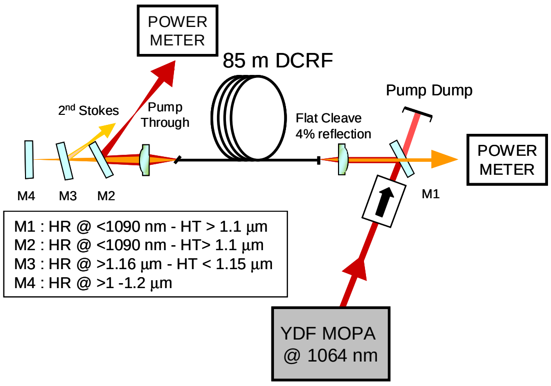

Fig. 1: Configuration of the cladding-pumped Raman Fiber laser.

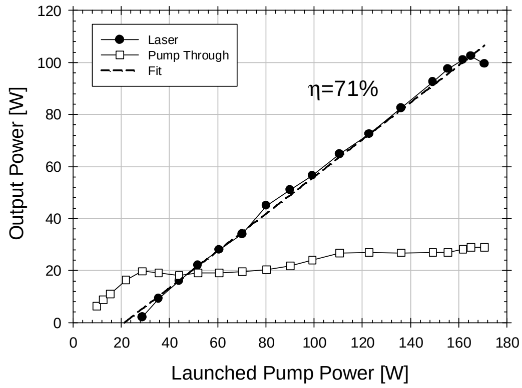

Fig. 2: Output Power and pump throughput vs. launched pump power.

In fig.2 we observe that the output power is limited and this is attributed to thermal lensing in the free-space isolator which degrades the beam quality and modifies the launch efficiency. Furthermore, we have measured the output beam quality at various output power. At lower output power the laser M^2 is ~1.35. This is to be compared the theoretical value for 1.37 for the LP_{01} mode at this wavelength for this fibre refractive index profile. Then, with the increased output power, we observe a slight degradation of the beam quality, with a M^2 of ~ 1.6 at 80 W output. Since in your laser cavity we do not have any spatial mode filtering, lasing can occur for some higher-order modes. Nonetheless, the beam quality is perfectly acceptable for many applications, and filtering can be easily implemented. Additional data will be provided at the conference.

We believe that even higher powers are possible with better design DCRF and higher pump power. For example, several pump sources can be spatially multiplexed to increase the pump powers as long as the light beams can be accommodated by the cladding dimension and numerical aperture of the DCRF. This approach potentially offers a route to extremely high power fiber laser source, limited only by the material damage of core and that even higher CW power will be reached in the very near future.

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