Contribution to the achievement of SDGs
by Furukawa Electric Group

Development of 10 W Output in 1550 nm Wavelength Region Fiber Light Source by Use of LMA-ErDFA Pumped by Raman Laser

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ABSTRACT Spatial radiation of lasers such as spatial optical communication, Light Detection and Ranging (LiDAR), is progressing in its market development for applications. In this case, a light source with a high output power and a Single-Mode (SM) characteristic is being increasingly demanded. We developed a prototype fiber amplifier with over 10 W of output power by pumping a Very Large Mode Area Er-Doped Fiber (VLMA-ErDF) using a high-power Raman laser named Cascaded Raman Resonator Laser (CRRL). An output with a 1.6 mJ of pulse energy, by amplifying the 2 μsec temporal width pulse by a similar pumping configuration was demonstrated in OFS Fitel, LLC. (OFS). This is also reported.

1. INTRODUCTION

Taking advantage of the characteristics of lasers, lasers are widely expanding in social implementation and applications including in the field of optical communications, as well as in the field of science and medical care such as microscopes and analytical equipment, and industrial fields where high-output power lasers are required for metal and material processing.

Lasers have the properties of being able to propagate through space over long distances due to their high energy. Therefore, high-sensitivity sensing and communication over long distances are available by using wavelength filters and interference measurements. Furthermore, with the advancement of unmanned and labor-saving systems, research and development into LiDAR is progressing, and it is playing a role in replacing human "eyes". LiDAR is utilized to measure the atmosphere and ground from the perspective of climate change and disaster prevention, aside of being applied as a sensor for autonomous cars and factory robots has also been demonstrated. In addition, preparing to Beyond 5G, to enable high-speed communication whch is difficult with radio waves, a technology using optical communication is currently under consideration which is necessary for artificial satellites, Unmanned Aircraft Vehicles (UAVs), drones, that fly in the sky including the stratosphere, and ground stations, and is also for mutual communication between flying objects (Figure 1).

In these systems, so far, lasers have mainly been used

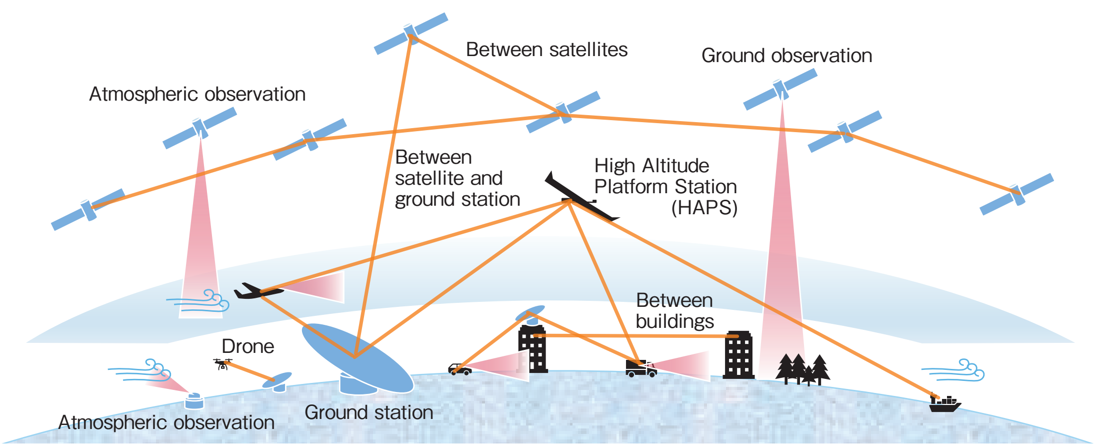

Figure 1 Image of free space laser applications.

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in limited environments such as in controlled indoors or factories. However, the requirements to emit light into space and to propagate it over greater distances are growing. The required characteristics for propagating laser light over longer distances are as follows:

(1) Good beam quality
(2) High output

Furthermore, assuming installation on a moving object,

(3) Small size
(4) Low power consumption

For these requirements, optical fiber amplifiers are expected to be used in the field of spatial radiation from the following characteristics.

i) High efficient optical amplification is possible
ii) Single-mode output is possible
iii) High output and heat dissipation can be compatible depending on the fiber length

On the other hand, within optical fibers, due to the small core diameter through which light propagates, the optical intensity density increases with increasing output. Then issues are created, such as degradation of output characteristics due to nonlinear effects and destruction of light. Therefore, we adopted a Cascaded Raman Resonator Laser (CRRL)[1)] as the pumping light source and the VLMA-ErDF as the gain fiber to fabricate a prototype of a fiber amplifier integrating CRRL+VLMA. This paper reports on the results of the work.

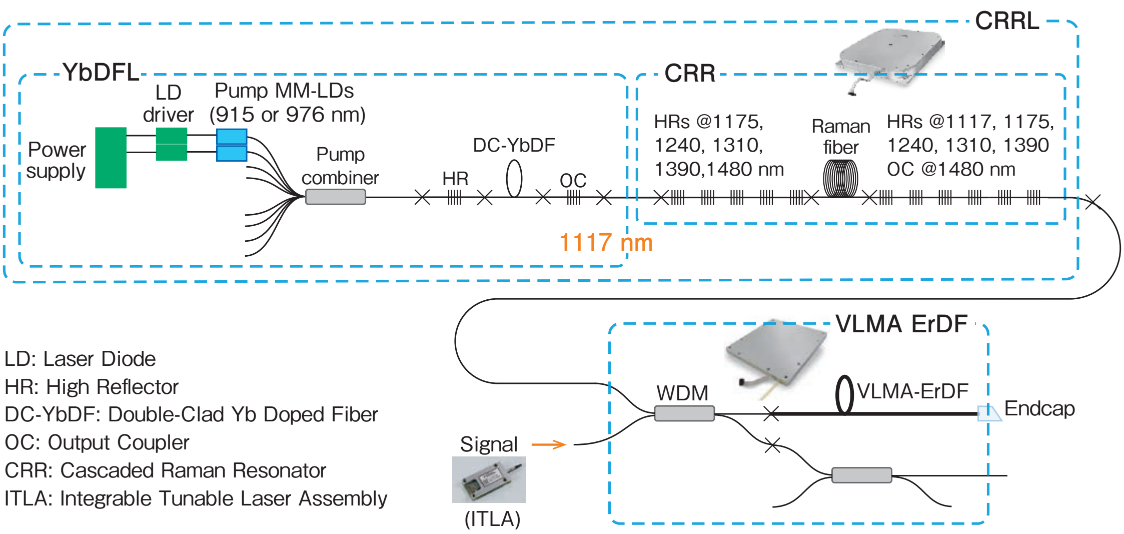
2. CONFIGURATION

The configuration of the prototype fiber amplifier integrating CRRL+VLMA is shown in Figure 2. The CRRL takes a Yb-Doped Fiber Laser (YbDFL) pumped by a Multimode (MM) semiconductor laser as a seed light source, and a light beam with a wavelength of 1117 nm is output from the YbDFL and input to the CRRL. Within the CRRL, a light beam with a wavelength longer than the incident 1117 nm oscillates due to Raman gain. The Raman gain on this light induces oscillation of even longer wavelength light. This repetition leads to the output of a light beam with 1480 nm of wavelength from the Single-Mode Fiber (SMF). In the VLMA section, the signal light to be amplified is superimposed with the 1480 nm light output from the described CRRL by a Wavelength Division Multiplexing (WDM) coupler and coupled to the VLMA-ErDF, then the signal light is amplified to be output. Since the CRRL output is the SMF output, the VLMA-ErDF enables core-pumping by combining it through the WDM coupler, and the length of the VLMA-ErDF can be shortened while maintaining the absorption and amplification rates. This makes available the reduction of the nonlinear effect and the fiber dispersion which are caused within the fiber. In addition, as the VLMA-ErDF has a core diameter of 50 μm, so output threshold for nonlinear effects and fiber destruction can be increased even during high-output amplification. Furthermore, by properly arranging the VLMA-ErDF, the single-mode output can be achieved.

3. RESULT

The power is supplied from an external input, and as shown in the above configuration, the 915 nm MM-Pump LD, LD driver, unitized CRRL, and VLMA-ErDF are boxed in a single-housing. To protect the fiber amplifier, a protection circuit is built-in so that it cuts off the output of the pump LD when the signal light input is lost. As the MM-Pump LD and LD driver generate heat, a cooling mechanism is necessary. Though the design is based on air cooling, but also allows for water cooling in preparation for future increases in output. The constructed fiber amplifier is shown in Figure 3. The dimension is 552 (W) × 102 (H) × 669 (D) mm.

As shown in Figure 4, the change in output versus the intensity of the 1480 nm light beam from the CRRL was measured. Though the light beam containing multiple wavelength components is output from the CRRL, only the intensity of the 1480 nm light beam component was calculated and plotted on the horizontal axis. The measured wavelengths were each 1545 nm, 1550 nm, and 1565 nm. The input light beam was a Continuous Wave



LD: Laser Diode
HR: High Reflector
DC-YbDF: Double-Clad Yb Doped Fiber
OC: Output Coupler
CRR: Cascaded Raman Resonator
ITLA: Integrable Tunable Laser Assembly

Figure 2 Configuration of CRRL + VLM amplifier.

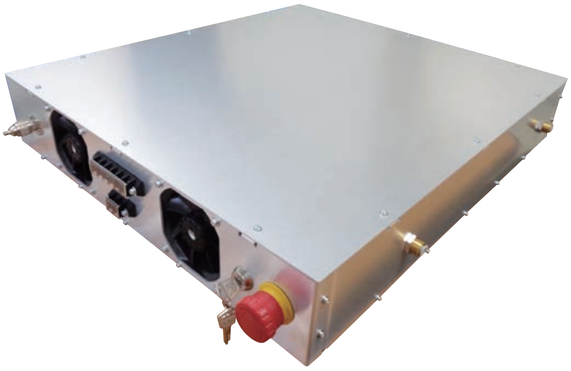


Figure 3 Photo of the prototype amplifier.

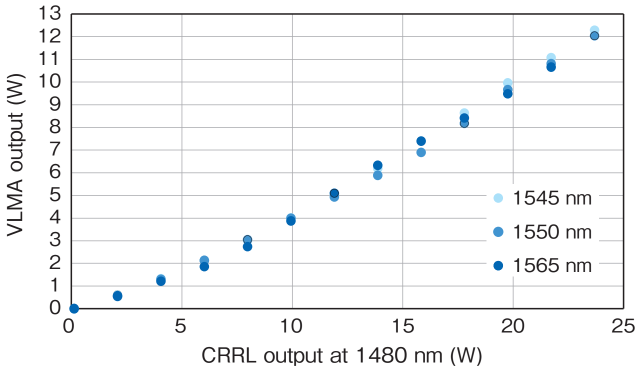


Figure 4 VLMA output depending on CRRL output.

(CW) light. The output of VLMA was also determined by calculating the power of the Amplified Spontaneous Emission (ASE) optical component separated from the spectral waveform obtained by an optical spectrum analyzer. The VLMA output power increased according to the CRRL output (equal to the amount of excitation light), and an output power exceeding 10 W was confirmed at either wavelength by inputting over 20 W of pump light.

The optical spectrum of the amplified output is shown in Figure 5. Through an Integrable Tunable Laser Assembly (ITLA), the wavelength of the input signal was changed to 1545 nm, 1550 nm, and 1565 nm and amplified to approximately 200 nW by a preamplifier before being input. Each light beam with 1545 nm, 1555 nm, and 1565 nm of wavelengths was amplified by this amplifier, and 20 nm of the amplified bandwidth was confirmed. The ratio of signal light to ASE light was over 40 dB.

The light output from the optical amplifier was collimated through a collimating lens and observed at a distance of 30 cm. The beam profile of the observed output light is shown in Figure 6. It was confirmed that the beam profile was almost a circle and of Gaussian distribution.

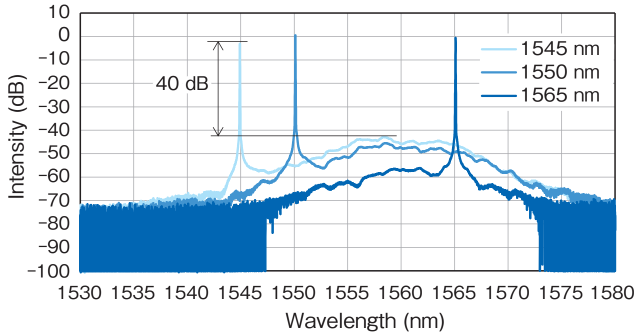


Figure 5 Output spectrum.

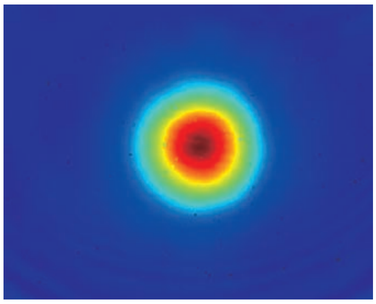


Figure 6 Observed beam profile.

4. AMPLIFICATION OF PULSED LIGHT

The development of an integrated CRRL + VLMA fiber amplifier for amplifying CW light was reported in the above chapters. Furthermore, an optical fiber amplifier using CRRL + VLMA for pulsed light has also been developed and reported[2)]. Recently, in a sensing field such as LiDAR, the amplification of a pulsed light with a narrow spectral line width and temporal width of several hundred nanoseconds to several ten milliseconds is in ever greater demand. So, at OFS laboratories, a pulsed light amplification with a temporal width of 1.24 μsec was demonstrated using the configuration shown in Figure 7[3)].

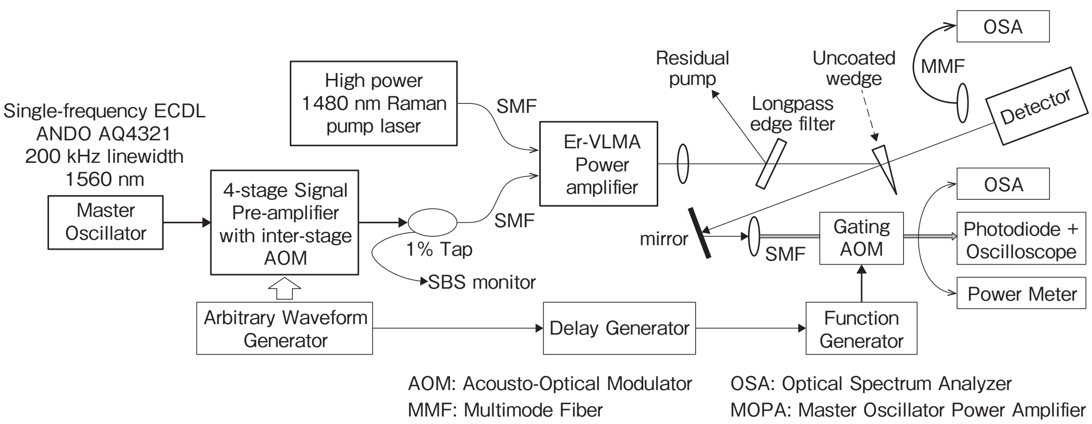


Figure 7 Schematics of experimental setup of VLMA fiber MOPA. including the output pulse diagnostic setup.

Figure 8 shows the measuring results of the pulse energy of the output pulse for 1480 nm pumping light while changing the pulse repetition frequency to 150 Hz, 1 kHz, and 5 kHz. At either repetition frequency, the pulse energy exceeding 1 mJ could be demonstrated. In particular, 1.6 mJ of the pulse energy was achieved at 1 kHz.

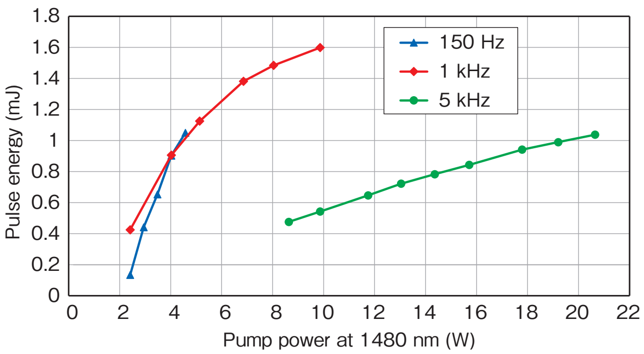


Figure 8 Power amplifier output pulse energy at 1560 nm for repetition rates of 150 Hz, 1 kHz and 5 kHz.

Figure 9 shows the time waveform when a repetition frequency of 1 kHz with a pulse energy of 1.6 mJ was output. Though the output from the preamplifier was 2.5 μsec, it was shortened to a pulse length of approximately 1.25 μsec at the final output.

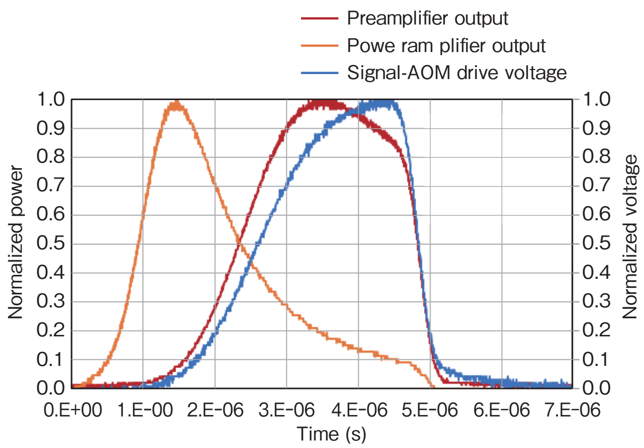


Figure 9 Normalized pulse waveforms at (i) the input to the signal-AOM, (ii) the output of the preamplifier, and (iii) the output of the power amplifier. Recorded during 1.6 mJ operation at 1 kHz.

5. SUMMARY AND FUTURE PROSPECTS

The optical fiber amplifier that was prototyped uses a 1480 nm Raman laser as a pumping light source and integrates a VLMA-ErDF having a large core diameter to suppress nonlinear effects in the fiber and to increase output. This optical fiber amplifier achieves an output of 10 W or more over a wide bandwidth from 1545 nm to 1565 nm. Furthermore, 1.6 mJ of pulse output energy with 1.48 μsec of pulse width was demonstrated at OFS.

Going forward, for both CW and pulsed signals, applications aimed at long-distance propagation are expected to expand. Even higher output while maintaining pure SM output is expected to be in demand. Already, an output power exceeding 100 W has been reported[4), 5)]. However, depending on the condition of the input signal light, nonlinear phenomena like Stimulated Brillouin Scattering (SBS) and effects of ASE light will be cited as issues. Further efforts to address these challenges are required.

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