Gain distribution in a short Raman fiber amplifier

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We provide the experimental characterization of the gain distribution in a short Raman fiber amplifier. An Optical Time Domain Reflectometry technique is used in order to monitor the power evolution along a 100 m germania-glass-core optical fiber amplifier. Thanks to this non-destructive method we have characterized the distributed Raman on-off gain spectrum along the length of the fiber with a resolution of 10 m. This measurement technique also allows us to measure a record peak Raman efficiency of 260 dB/km/W for this fiber.

Introduction

Because of the flexibility in the choice of the amplification window that depends only on the pump wavelength, and of the currently available higher pump power, Raman fiber amplifiers (RFA) have known deep investigations. Beside distributed RFA where the transmission fiber itself is used as the amplifying medium, one finds discrete RFA design, which is also used to compensate dispersion [1]. Nevertheless, until now the fiber length required to provide reasonable gain was several kilometer long because of the relatively weak Raman gain efficiency of classical optical fiber already available.
Here, we show and characterize a discrete RFA based on 80%-Germania-glass-core fiber which exhibit astoundingly high Raman gain [2]. However the parallely high fiber linear losses and potential lack of uniformity in the Raman gain of this new kind of fiber requires very careful design. We apply here a technique that we developed to characterize the distribution of the gain in the fiber [3,4] to determine optimal length of the fiber and pump power required to maximize the gain according to the pump and signal wavelength.

Experimental Set-up

Our experimental set-up is shown on fig. 1. It is based on a classical commercially available optical time-domain reflectometer (OTDR) modified in order to use narrow bandwidth tunable source instead of the broadband LED integrated inside the equipment. The optical pulses sent by the OTDR are detected after passing through a circulator by a high bandwidth photo-detector (PD) that is used to provide the modulation scheme for an acousto-optic modulator (AOM) via a pulse generator. The AOM then modulates a semi-conductor tunable external cavity laser source (ECL) amplified by a forwardly pumped RFA which provides enough energy to the short pulses and slightly broadens the spectrum of the source in order to reduce the coherence noise related to this kind of measurement [5]. The so-generated optical pulses are launched in the fiber under test after passing through a second circulator and a

wavelength division multiplexer (WDM) where they are coupled with a tunable unpolarized Raman fiber laser pump. The optical pulses are then amplified by stimulated Raman scattering (SRS) inside the fiber and continuously Rayleigh backscattered towards the OTDR. The amplified Rayleigh signal is then directed by the circulators to the OTDR for detection after passing through a narrow band tunable optical thin film filter that eliminates the residual Rayleigh backscattered pump power as well as the spontaneous Raman backscattering generated in the fiber that could perturb or damage the OTDR.
In all our measurement the pulses duration was set to 100ns, which is the minimum duration allowed by the AOM whose rise time is 50ns. This gives a spatial resolution of 10m, giving 10 significant points of measurement in our fibers that are 100m long.

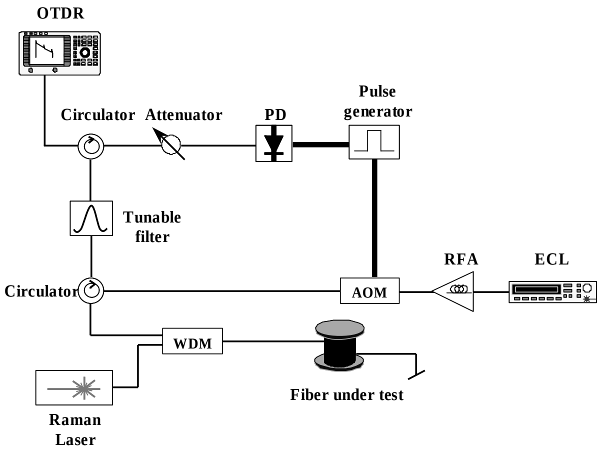

fig 1: experimental set-up

Results and discussion

Fig 2 shows the gain profile along the fiber when the pump power is raised. One can notice that for high pump power the amplifier saturates because of the depletion of the signal by the generation of a second Stokes order SRS.

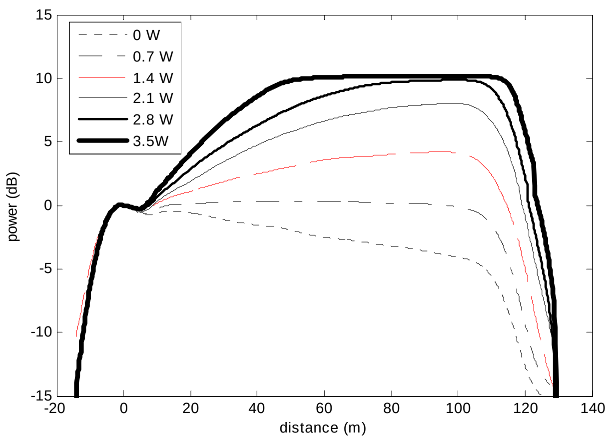

fig 2: distribution of the power along the fiber for various pump power intensities

Fig 3 shows the Raman on/off gain spectrum distribution characteristics along the fiber.

The main source of error in our experimental set-up comes from the coherence noise due to the narrow bandwidth of the signal used for the measurement. We estimate this systematic error thanks to a least square fit of the gain with the theoretical model of SRS which leads to a maximum mismatch with the experimental curve of 6%. This fit also allows determining the Raman gain efficiency spectrum and the losses at the pump wavelength. For a pump power of 2W pump losses seems to depend on the signal wavelength what shows that there is pump depletion

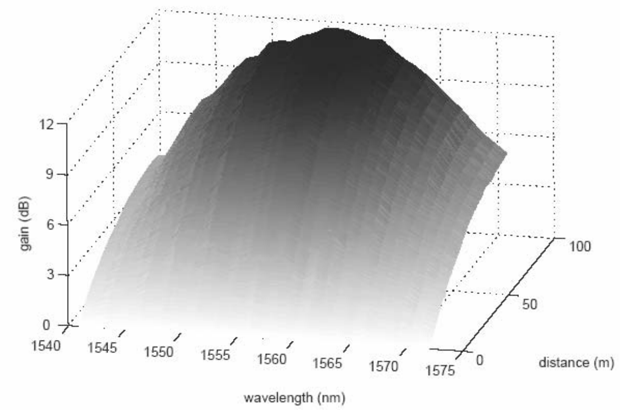

fig 3: distribution of the gain spectrum along the fiber

The Raman on/off gain for a signal wavelength l after a distance z is given by [6]:

$$G(\lambda, z) = \exp\left\{\frac{C_R(\lambda)P}{K}\left[\frac{1-\exp(-\alpha_P z)}{\alpha_P}\right]\right\} \qquad (1)$$

where C_R is the Raman efficiency coefficient, K is the depolarisation factor 2 in our case, P is the injected pump power, α_P is the linear losses at the pump wavelength.
With a suitable least square fit of eq 1 it is possible to determine the Raman efficiency C_R. The result of this data processing is shown in fig 4.
The peak value of the gain is around 260dB/km/W what is consistent with previous measurement on this fiber [2].

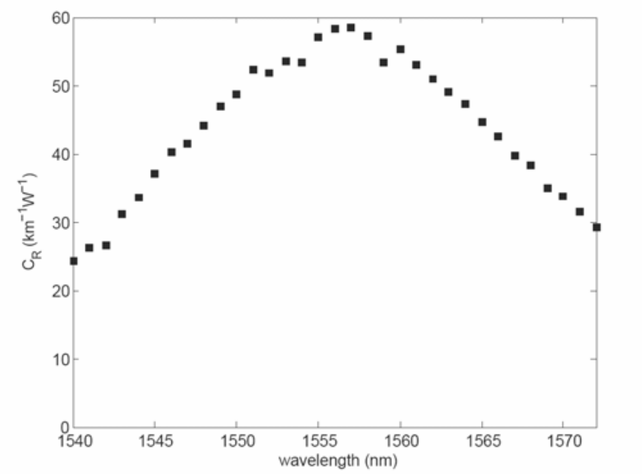

fig 4: Raman efficiency spectrum

Conclusion

In this paper we show how to apply an OTDR based technique to the design of a short discrete Raman fiber amplifier. This kind of measurement reveals features of the Raman gain process inside the optical fiber. We provided the distributed gain spectrum characteristics of the RFA. We also show the saturation characteristics of the amplifier due to the signal depletion by second order Stokes generation.

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