Raman Gain and Random Distributed Feedback Generation in Nitrogen-doped Silica Core Fiber

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In the present paper we demonstrate the random generation in the N-doped optical fiber. The N-doped fiber has several times higher Rayleigh scattering coefficient than standard telecommunication fibers. Due to the higher Raman gain coefficient of 7.5 (km W)$^{-1}$ the efficient random generation is achieved in shortest up to date fiber of length just 500 meters. The Raman gain coefficient in N-doped fiber is measured for the first time to our knowledge.

Introduction

The concept of a random distributed feedback lasing in optical fibers has been demonstrated recently [1]. A number of different random DFB fiber lasers has been demonstrated so far including tunable, multiwalength, cascade generation, generation in different spectral bands, generation in hybrid FBG-based and random cavities etc. [2-12].

All demonstrated systems are based on standard low-loss germanium doped silica core fibres having relatively low Rayleigh scattering coefficient. Thus, the typical length of random DFB fiber lasers is in the range from several kilometres to tens of kilometres to accumulate enough random feedback for the generation. It is of interest to demonstrate a random lasing in a fiber media having higher Rayleigh scattering coefficient and thus providing larger random feedback.

One of potential interesting fibers is nitrogen doped (N-doped) silica core optical fiber [13]. The N-doped fiber has a several times higher Rayleigh scattering coefficient compared to standard telecommunication fibres. For N-doped fibers, Rayleigh scattering determines the optical losses in the range 1.0-1.2 μm with the coefficient C_R=5.4 dB/km*μm. In the wavelength range 1.2 and 1.55 μm, the optical losses in N-doped fiber are defined by hydrogen-containing groups. So it could be feasible to achieve random generation in N-doped fiber in 1um region if Raman gain is high enough. Note, that nonlinear properties of N-doped fiber including Raman gain coefficient are not known so far.

In the present paper we demonstrate for the first time to our knowledge the random generation in N-doped optical fiber.

Experimental Setup

We implement here one arm single side pump scheme of random DFB fiber laser [5]. The N-doped fiber is pumped by the 10 W polarized ytterbium fiber laser, generating at 1064 nm. Collimated output beam with maximum diameter around 2 mm with the help of microlens was focused onto the entrance end of the fiber span. Radiation from the output end of the fiber span was collimated again to simplify the registration process.

Three Rugate notch filters were used for the separation of Raman Stokes components from the pump radiation and to prevent the shutdown of the laser due to the backscattered Stokes components.

In our experiments we used 500 meter long N-doped silica core fiber manufactured by IRE RAS. The fiber has a core of 2.5um, and 0.97km^{-1} and 0.78km^{-1} linear losses at pump and Stokes wavelength, correspondingly. In the investigated wavelength range N-doped fiber is a single mode. Both outputs of the fiber spans were terminated by the angle polished connectors to avoid 4% Fresnel reflection which is crucial for the RDFB laser operation.

Output power and optical spectra of residual pump and generated Stokes waves were measured at both forward (output end of fiber span) and backward (input end of fiber span) directions.

Results and Discussions

Firstly, we have performed Raman gain measurement in this fiber follow technique presented in [14]. The measured Raman gain coefficient is 7.5 (km W)$^{-1}$. This value is several times higher than in standard fibers.

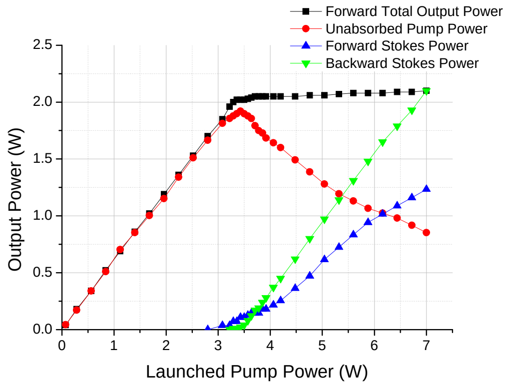

Fig. 1. Generated and pump power of the N-doped random DFB fiber laser.

At a pump power around 3 W, the random generation of Stokes wave starts. There was only one Stokes wave component we managed to achieve due to the upper power limit of the pump laser, contrary to previous studies where cascaded generation has been demonstrated [5]. Power characteristics measured in both directions can be found on Figure 1. The threshold pump value was around 3.4 W coupled to the fiber pump power. The Stokes wave power is up to 2.0 W and 1.25 W in backward and forward directions respectively. Output power in backward direction (green reversed triangles) increases linearly with slope efficiency as high as 58%. At the same time, total forward output power (black squares) consisted of two components: unabsorbed pump power (red circles) and Stokes power (blue triangles).

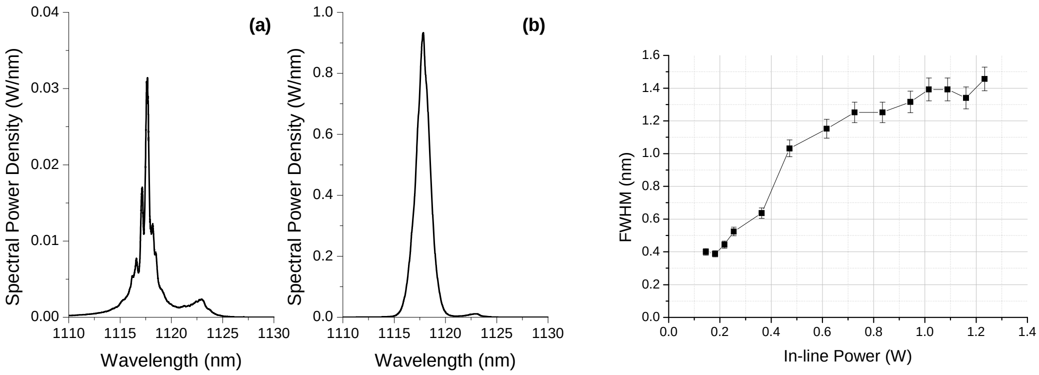

Fig. 2. Random DFB fiber laser spectrum generated in 500 m long nitrogen doped fiber near (a) and high above (b) the threshold. (c) Spectral width dependence on the generated power.

Difference in forward and backward intensities can be explained in terms of amplification length L_{RS} [1]. While the fiber length is less than L_{RS}, Raman gain is higher than the optical losses for the generated wave. Near the threshold the amplification length can be found as $L_{RS}=ln(g_R P_0/\alpha_s)/\alpha_p$. Here g_R – the Raman gain coefficient, P_0 – the pump power, α_s and α_p – the linear losses at the wavelengths of pump and Stokes respectively. For the fiber under study, the amplification length is around 3.6 km, so a 500 m segment is pumped almost uniformly. At the initial stage the generated power in forward and backward Stokes waves are practically the same, as the same amplification for both directions is provided. At higher pump level, the pump wave depletion change the balance between forward and backward Stokes waves, and output power of backward wave becomes higher. Note, that in pure random DFB fiber laser without parasitic lumped losses, the output power in the backward direction should be always higher than in forward direction following analytical considerations presented recently in [15].

The generation is located mainly on one spectral peak, Fig. 2a,b. The spectral width is of order of 1 nm and depends nonlinearly on the generated power, Fig.2c. The origin of the spectrum broadening should be further investigated.

Conclusions

In this paper we demonstrate the random generation in N-doped optical fiber. The shortest for our knowledge random distributed feedback Raman fiber laser is demonstrated having just 500 meters length. Despite higher optical losses, the generation efficiency of 58 % is achieved. The high generation efficiency is possible due to high Raman gain coefficient of 7.5 (km W)$^{-1}$ being several times higher than in standard telecommunications fiber. The Raman gain coefficient is measured for the first time for N-doped fiber.

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