SUMMARY We design and demonstrate a high repetition-rate similariton generation system using normal dispersion fiber amplifiers (NDFA’s). We numerically calculate the pulse evolution in NDFA’s and clarify the condition to generate similariton pulses in a finite-length NDFA. Then we design the similariton generation system in consideration of the use of Erbium-doped fibers (EDF’s) and show that a km-long fiber amplifier with low normal dispersion can generate a high repetition-rate similariton train from practical pico-second pulse sources. In the experiment, we demonstrate a 10-GHz similariton source using a 1.2-km-long EDF. For application to multi-wavelength light sources, we measure the bit-error rate of the spectrally sliced similariton, and show that it exhibits low-noise performance, which is attributed to the spectral flatness.

key words: optical fiber amplifier, self-phase modulation, similariton, spectrum broadening

1. Introduction

When a high-intensity optical short pulse is led to a normal dispersion fiber amplifier (NDFA), the pulse spectrum broadens through self-phase modulation (SPM) and the waveform gradually evolves into a parabolic shape. Then, the pulse accumulates linear frequency chirp through SPM while keeping the parabolic shape with help of the gain, and the pulse spectrum broadens smoothly without ripples. This parabolic pulse formed in NDFA’s is known as ‘similariton.’

The formation of similariton pulses was discovered numerically in [1], and its mathematical treatment was given by Fermann et al. [2] and Kruglov et al. [3]. They used the nonlinear Schrödinger equation with gain and showed that an asymptotic solution can exist in normal dispersion regime. The experimental demonstration of similariton generation was successfully conducted in a 3.6-m Ytterbium-doped fiber amplifier with a 200-fs pulse train [2].

The similariton has several interesting properties originating from its asymptotic behavior: The pulse evolution is governed mainly by the input pulse energy and less dependent on the input pulse width and shape when the length of the NDFA is long enough. Although the pulse energy increases extremely as the pulse propagates, the similariton can prevent disastrous waveform distortion even under strong nonlinear effects. Owing to these features, similariton pulses have been used mainly for high-intensity, ultra-short pulse generation and amplification.

Also similariton generation has potential applications in optical communication systems. The flatly broadened spectrum could be directly applied to multi-wavelength sources [4]–[6] with spectrum slicing. Moreover, the optical signal processing based on the SPM-induced spectrum broadening, which includes pulse compression [7], waveform conversion [8] and signal regeneration [9], is made possible just by replacing nonlinear fibers with NDFA’s in previous experimental setups. In these applications, the immunity of similaritons to the input pulse shape is advantageous in practical use, and as will be shown later, the flat spectrum can improve the noise performance.

However, the condition of similariton generation in optical communication systems is totally different from that in the previous experiment [2]. Major points are twofold: (a) The repetition rate of pulses is high (ten gigahertz or higher), and hence the pulse energy is about two orders of magnitude lower than the previous experiment. (b) The input pulse width is over several pico-seconds, which is one order of magnitude wider than the previous experiment. Due to these reasons, the formation of similaritons has never been observed in conventional optical amplifiers used in optical communication systems. For similariton generation, therefore, a special design of NDFA is indispensable.

In this paper, we investigate similariton generation for application in optical communication systems. We start with an analytic form of similariton in a normalized NLSE and discuss fiber parameters required to generate the similariton by using a practical pulse source and a fiber amplifier. Then we demonstrate 10-GHz similariton generation by using an Erbium-doped fiber. Following this, we assess the signal quality of spectrally sliced similariton, and show that the high spectral flatness of similariton is advantageous for application to multi-wavelength pulse sources.

The organization of this paper is as follows. In the next section, we introduce the property and theoretical background of similariton. In Sect. 3, we design the similariton generation system in consideration of the use of practical fiber amplifiers. In Sect. 4, we report on the experiment of
10-GHz similariton generation and its application to a multi-wavelength transmitter. In Sect. 5, we discuss the pros and cons of the use of similariton. Finally we summarize this paper in Sect. 6.

2. Asymptotic Solution of Optical Pulse in Normal Dispersion Fiber with Gain

We start with an analytical expression of similariton solutions in a normalized form [1]–[3]. The pulse evolution in an NDFA is described with the nonlinear Schrödinger equation (NLSE) with gain:

\[
i \frac{\partial A}{\partial z} = \frac{\beta_2}{2} \frac{\partial^2 A}{\partial t^2} - \gamma |A|^2 A + i g A,
\]

where \( A \) is the electric field, \( z \) is the distance along the fiber, \( t \) is time, \( \beta_2 \) is the group delay dispersion (GVD), \( \gamma > 0 \) is the nonlinear coefficient, and \( g > 0 \) is the gain per unit length.

In order to generalize the discussion, we normalize the modified NLSE by introducing the following dimensionless variables:

\[
\xi = gZ + \log \left( \frac{\gamma E_{in}}{2 \sqrt{\beta_2 g}} \right),
\]

\[
U(\xi, \tau) = \sqrt{\frac{\gamma}{g}} A(Z, T),
\]

\[
\tau = \sqrt{\frac{g}{\beta_2}} T,
\]

where \( \xi \) is the normalized distance, \( U \) is the normalized electric field, \( \tau \) is the normalized time and \( E_{in} \) is the pulse energy at \( Z = 0 \). Noted, that the definition of the normalized distance, \( \xi \), contains the input energy. This normalization allows us to reduce the number of parameters in the normalized equation, and the similariton solution is expressed as a function of only \( \xi \) as shown later. Obviously, \( \xi \) is not necessarily zero at \( Z = 0 \). We denote it by \( \xi_{in} \). It is also noted when \( \xi_{in} \) is specified, \( E_{in} \) is determined in the original NLSE.

Substituting Eqs. (2)–(4) into Eq. (1), we obtain the normalized modified NLSE given by

\[
i \frac{\partial U}{\partial \xi} = \frac{1}{2} \frac{\partial^2 U}{\partial \tau^2} - |U|^2 U + i \frac{\partial U}{\partial \tau}.
\]

This equation supports the following asymptotic self-similar solution (i.e., similariton solution) in the limit of \( \xi \to \infty \).

\[
U(\xi, \tau) = \begin{cases} 
U_0(\xi) \sqrt{1 - \left( \frac{\tau}{\tau_p(\xi)} \right)^2} \exp \left[ i \left( \varphi(\xi) + \chi \tau^2 \right) \right] & \text{for } |\tau| \leq \tau_p, \\
0 & \text{for } |\tau| > \tau_p,
\end{cases}
\]

with

\[
U_0(\xi) = \frac{1}{\sqrt{2}} \exp \left( \frac{\xi}{3} \right),
\]

\[
\tau_p(\xi) = 3 \exp \left( \frac{\xi}{3} \right),
\]

\[
\varphi(\xi) = \frac{3}{4} \exp \left( \frac{2\xi}{3} \right),
\]

\[
\chi = -\frac{1}{6},
\]

where \( U_0(\xi) \) is the peak amplitude, \( \tau_p(\xi) \) is the pulse width, \( \varphi(\xi) \) is the phase shift, and \( \chi \) is the frequency chirp. It is noted that Eq. (6) is not an exact solution to the modified NLSE, Eq. (5). However, if we launch an optical pulse into the NDFA, it approaches to the similariton solution given by Eq. (6) after propagation of a sufficient distance.

Equation (6) indicates that the intensity waveform is a parabolic function. During the pulse evolution, the solution maintains its parabolic shape self-similarly, and the peak power and the pulse width increase exponentially.

From the phase term of Eq. (6), the instantaneous angular frequency \( \Omega(\xi, \tau) \) can be derived as:

\[
\Omega(\xi, \tau) = -\frac{\partial}{\partial \tau} \left( \varphi(\xi) + \chi \tau^2 \right) = \frac{\tau}{3}.
\]

This indicates that the solution has linear up-chirp.

The spectrum of the similariton solution, i.e., the Fourier transform of Eq. (6) can be derived by the method of stationary phase [3] as:

\[
\hat{U}(\xi, \Omega) = \frac{1}{\sqrt{2\pi}} \int U(\xi, \tau) \exp i\Omega \tau d\tau = \begin{cases} 
\left( \frac{1 - i \sqrt{\frac{\Omega}{3}}}{2} \right) \exp \left( \frac{\Omega}{3} \right) \exp i \left( \varphi(\xi) + \frac{\Omega^2}{2} \right) & \text{for } |\Omega| \leq \Omega_p, \\
0 & \text{for } |\Omega| > \Omega_p,
\end{cases}
\]

where

\[
\Omega_p(\xi) = -2\chi \tau_p = \exp(\xi/3).
\]

The spectral width \( \Delta \Omega \) can be approximately obtained from Eq. (12) and Eq. (13) as

\[
\Delta \Omega(\xi) \sim 2\Omega_p = 2 \exp(\xi/3).
\]

As an example, we calculate the pulse evolution in an NDFA with the following parameters: \( \beta_2 = 10 \times 10^{-3} \text{ps}^2/\text{m} \), \( \gamma = 10 \times 10^{-3} \text{W}^{-1} \text{m}^{-1} \), and \( g = 1 \text{m}^{-1} \). The input pulse is a 300-fs Gaussian pulse and its energy is 20 pJ. These parameters
correspond to $\xi_{in} = 0$ and $\tau_{in} = 3$, where $\tau_{in}$ is normalized pulse width. As shown in Fig. 1(a), the input pulse evolves into a similariton with a parabolic waveform. Simultaneously, the spectrum is broadened through SPM. Since SPM on parabolic pulse causes linear chirp, the similariton has a flatly broadened spectrum, as is shown in Fig. 1(b).

### 3. Similariton Generation in Practical Fiber Amplifiers

As mentioned in the previous section, similariton pulses have a flatly broadened spectrum with a linear frequency chirp, and they have less dependence on the input pulse shape. Any input pulse approaches asymptotically to the similariton solution in the limit of the propagation distance to infinity.

From a practical point of view, however, the application of similariton pulses is not straightforward because actual NDFA’s have a finite length, a finite gain, and a finite output power. Therefore, the input pulse does not necessarily converge to the similariton solution. In this section, we first discuss the condition for the similariton generation in a finite-length NDFA, and then show a design example.

#### 3.1 Convergence to Similariton Solution in NDFA’s

We investigate the condition for initial pulses to converge to similariton solution. In order to simplify the discussion, we set the total optical gain $G = \exp(gL)$ to 100 (20 dB), taking a typical gain of practical EDFA’s into account. We calculate the pulse evolution in NDFA’s by changing the energy and the width of the input pulse. In the normalized NLSE, the pulse energy and the pulse width are expressed by the normalized distance at the input, $\xi_{in}$ and normalized full width at half maximum (FWHM) of input pulse, $\tau_{in}$, respectively.

We use chirp-free Gaussian pulses as input pulses.

Figures 2(a)–(c) show the evolution of 10-dB bandwidths along the fiber when $\xi_{in}$ is (a) $-3$, (b) 0, and (c) 3, respectively. The spectral width of the similariton solution given by Eq. (11) is also shown by broken curves. In Fig. 2(a), the spectral widths are almost constant along the fiber. This means that the similariton is not formed because the pulse energy is too low. On the other hand, in Figs. 2(b) and (c), the 10-dB bandwidths increase with the evolution and gradually approach to those of the similariton solution. This indicates that the initial pulse converges to the solution and becomes a similariton.

In order to clarify the range of parameters of initial pulses for similariton generation, we calculate the spectral widths of output pulses of NDFA’s by changing $\xi_{in}$ and $\tau_{in}$. The results are shown in Fig. 3. It is clearly seen that the bandwidth in the region of $\xi_{in} \ll 0$ is dependent on $\tau_{in}$. On the other hand, by increasing $\xi_{in}$, such dependence gradually disappears for the initial pulse width $\tau_{in} \geq 1$. From Fig. 3, it is found that the similariton is formed from initial pulses with $\xi_{in} \sim 0$ and $\tau_{in} = 1–4$. Moreover, as $\xi_{in}$ increases, broader input pulses can converge to similariton solution.

#### 3.2 Design Guideline of NDFA’s

Next, we determine real parameters of NDFA’s so that they satisfy the condition for convergence to the similariton solution.

![Fig. 3](image-url) Calculated 10-dB bandwidth in normalized unit as functions of $\xi$.

The optical gain $G$ is set to 100. Gaussian pulses are used as input pulses to the NDFA. The lower horizontal axis: $\xi$ at the input end of the NDFA. Broken line: full spectral width of the similariton solution given by Eq. (14).

![Fig. 2](image-url) Evolution of 10-dB bandwidth along the fiber. (a) $\xi_{in} = -3$. (b) $\xi_{in} = 0$. (c) $\xi_{in} = 3$. $G$ is 100 (20 dB). Broken line: full spectral width of the similariton solution given by Eq. (11). Marks are for clarity.
Here, we consider two possible situations for the design: (a) We determine the pulse parameters for a given set of parameters of NDFA's. (b) We determine the parameters of NDFA's for a given set of parameters of an initial pulse.

The design procedure for (a) is as follows. First, we determine a set of normalized parameters \((G, \xi_{\text{in}} \text{ and } \tau_{\text{in}})\) as discussed in Sect. 3.1. Then we derive the pulse energy and the pulse width using Eqs. (2) and (4).

\[
E_{\text{in}} = \frac{2\sqrt{\beta_2 g}}{\gamma} \exp(\xi_{\text{in}}),
\]

\[
T_{\text{in}} = \sqrt{\frac{2g}{\beta_2}} \tau_{\text{in}},
\]

where \(T_{\text{in}}\) is the FWHM of the input pulse. Thus the pulse energy and the pulse width are uniquely given.

On the other hand, the design procedure for (b) is slightly complex. First, we determine a set of normalized parameters \((G, \xi_{\text{in}} \text{ and } \tau_{\text{in}})\) as discussed in Sect. 3.1. Second, we calculate the fiber parameters from Eqs. (2) and (4) as follows:

\[
\beta_2 L = \left(\frac{T_{\text{in}}}{\tau_{\text{in}}}\right)^2 \log G,
\]

\[
\gamma L = \frac{2 \log G}{E_{\text{in}}} \tau_{\text{in}} \exp(\xi_{\text{in}})
= \frac{2G T_{\text{in}} \exp(\xi_{\text{in}})}{P_{\text{out}}} \tau_{\text{in}},
\]

where the repetition rate and the pulse width of the input pulse are \(f_{\text{rep}}\) and \(T_{\text{in}}\), respectively and the output power of the NDFA is \(P_{\text{out}}\). Since the above conditions determine only the total amounts of GVD and Kerr effect (i.e., \(\beta_2 L\) and \(\gamma L\)), there remains one degree of freedom. Therefore, we have to determine these parameters in such a way that they are within the range of practicable fibers.

A design example for the situation (b) is shown below. We set \(G = 100\) (20 dB), \(\xi_{\text{in}} = 0\), and \(\tau_{\text{in}} = 3\) for the fast convergence to similariton solution with a small input pulse energy. Then we assume that \(f_{\text{rep}}\) is 10 GHz, \(T_{\text{in}}\) is 2 ps, and \(P_{\text{out}}\) is 300 mW. From Eqs. (17) and (18), \(\beta_2 L\) and \(\gamma L\) are found to be 2.0 ps\(^2\) and 20 W\(^{-1}\), respectively. Thus a km-long, highly-nonlinear, and low-normal-dispersion fiber amplifier satisfies the condition for high repetition-rate similariton generation from pico-second pulses.

Figure 4 shows the calculated pulse evolution in the designed NDFA [10]. As is clearly seen in Fig. 4(a), the incident pulse changes its waveform into a parabolic shape and it propagates maintaining its shape. The output spectrum shown in Fig. 4(b)(iii) has a very flat shape and its spectrum ripple is significantly suppressed unlike the broadband spectrum generated from normal dispersion fibers without gain [6]. The 10-dB spectral width is 2.4 THz, which corresponds to 19 nm in 1550-nm wavelength region. It is noted that the calculated waveform and spectrum match well with the analytic solutions given by Eqs. (6) and (12), which are shown by open circles in Fig. 4.

Next, in order to examine the dependence of the spectrum on the input pulse, we carried out numerical simulations for various input pulse widths while keeping the input pulse energy constant. As is shown in Fig. 5, the variation in 10-dB bandwidths is only 3.6% when the pulse width increases from 1 ps to 3 ps. This means that the spectral width can be stabilized by keeping the pulse energy constant even if the initial pulse width changes. This property originates from the fact that the input pulse converges into the similariton solution and the solution depends only on the input pulse energy [2], [3]. This stabilization of the spectral width is another advantage of the spectrum broadening using NDFA's because this property may relax the requirement to the specification of the input pulse.

4. 10-GHz Similariton Generation Using a 1.2-km EDF

In this section, we generate 10-GHz similariton train by using a 1.2-km long Erbium doped fiber amplifier and evalu-
ate the flatly broadened spectrum for application to multi-wavelength sources [11].

Figure 6(a) shows the experimental setup. As a seed pulse, we used an optical pulse train from a mode-locked laser diode (MLLD). The repetition rate, the pulse width, and the center wavelength were 9.953 GHz, 2.4 ps, and 1552 nm, respectively. Then, we launched the pulse to a 1.2-km Erbium doped fiber (EDF). The dispersion, the dispersion slope, and the nonlinear coefficient were 1.3 ps$^2$/km, 0.061 ps$^3$/km, and 13.4 W$^{-1}$km, respectively. The input average power was 1.6 dBm and the gain was 21 dB. These conditions correspond to the normalized parameters of $\xi_{in} = -0.86$ and $\tau_{in} = 4.2$. The spectral width of the analytic solution is 2.1 THz, which corresponds to 17 nm in 1552-nm wavelength region.

During propagation in the EDF, the input pulse changes its waveform and spectrum toward a similariton with a broadband spectrum. At the output end, the 10-dB spectral bandwidth was 18.6 nm as shown in Fig. 6(b). The high spectral flatness originated from linear frequency chirp of the similariton. It is noted that a small oscillatory structure is seen at the seed wavelength in a close-up view of Fig. 6(b).

This is due to the interference among the similariton and the satellite pulses, which were generated in the MLLD. Moreover, the asymmetry of the spectrum is mainly caused by the gain characteristics of the EDF.

Next, we investigated the applicability to a multi-wavelength pulse source. We sliced the spectrum with an optical bandpass filter (OBPF) whose bandwidth is 0.23 nm. Then we modulated the sliced pulse train with a 2$^{31}$-1 pseudo-random bit sequence to compose a 10-Gb/s RZ transmitter. To evaluate the intensity noise of the sliced pulse, we measured the $Q$ factor as a function of the wavelength of the OBPF. The result is shown by open circles in Fig. 6(c). A high $Q$ factor of over 25.3 dB was realized in the almost whole bandwidth.

In order to compare the performance with the previously reported method, we replaced the EDF by a normal dispersion, dispersion-flattened fiber (DFF) without optical gain [6] and generated a broadband spectrum from the same pulse source (Fig. 7(a)). As shown in Fig. 7(b), the spectrum has a small oscillatory structure and the 10-dB spectral width was slightly wider than that of the similariton. The $Q$ factor of the sliced pulse, which is shown by open circles in Fig. 7(c), varies with the wavelength and is degraded to 22.3 dB.
The improvement of the noise performance by using the similariton (and the degradation of the $Q$ factor in the previous method) can be explained from the spectral flatness. If the broadened spectrum has a ripple, its position is a function of the seed pulse power and the ripple moves with a slight change of the pulse power. The spectral density in turn drastically changes near the valley of the ripple. In this way, the intensity noise of the input pulse is enhanced through the movement of the ripple position. On the contrary, if the pulse has a smooth spectrum, this kind of noise enhancement never occurs.

The noise enhancement factor can be evaluated with the modulation gain [12], which is defined by $g_{\text{noise}}(\lambda) \equiv [\Delta P_S(\lambda)/P_S(\lambda)]/\Delta P_0/P_0$. Here, $P_S(\lambda)$ and $P_0$ denote the optical intensity of a sliced pulse at the wavelength $\lambda$ and that of the seed pulse, respectively. $\Delta P_S(\lambda)$ corresponds to the change in $P_S(\lambda)$ when $P_0$ increases by $\Delta P_0$.

In order to calculate $g_{\text{noise}}$, we simulated the pulse propagation in EDF and DFF. We experimentally measured the waveform and the chirp of the seed pulse and used them for the simulation [13]. We took into the gain distribution along the EDF and neglected the gain dispersion. Figure 8 shows the $g_{\text{noise}}$ calculated by setting $\Delta P_0/P_0$ to 1%. The $g_{\text{noise}}$ of the EDF (solid line) is less than 0 dB in the almost entire spectrum. On the other hand, the $g_{\text{noise}}$ of the DFF (dotted line) fluctuates and increases up to 8.1 dB at 1546 nm, 3.7 dB at 1550 nm and 9.5 dB at 1557 nm, respectively. These wavelengths correspond to the local minima of $Q$ factor in Fig. 7(c).

We should note the relationship between $Q$ factor and modulation gain. If $Q$ factor depended only on the intensity noise of the pulse source, we could quantitatively compare the $Q$ factor by using modulation gain. However, $Q$ factor also depends on other noise sources such as amplified spontaneous emission (ASE) noise of optical amplifiers, thermal noise and jitter of transmitters and receivers, and so on. In our experiment, the similariton-based source had small modulation gain but included more ASE noise. As a result, the improvement of $Q$ factor (approximately 3 dB) by the use of similariton is smaller than the improvement of modulation gain. Although further discussion is required to quantitatively validate the $Q$-factor improvement, we could conclude quantitatively that small spectral ripples enhance intensity noise and flatly broadened spectrum is suitable to realize a low-noise multi-wavelength source.

5. Discussion

As was mentioned in Introduction, the spectrum-broadening technique based on similariton generation has various applications. In this section, however, we focus on the application to multi-wavelength sources and discuss the pros and cons in comparison with other SPM-based fiber devices.

A major difference from SPM-based fiber devices reported previously is that the gain fiber is used. Therefore, the similariton-based multi-wavelength source suffers from the degradation of SNR due to amplified spontaneous emission (ASE) noise. However, the discussion of SNR is not so simple because the system is nonlinear. In fact, as shown in the above experiments, the degradation of SNR is mainly caused by the deterministic noise enhancement due to the modulation gain, and the influence of ASE noise was less significant. Thus the use of gain fibers does not always result in worse SNR. According to our numerical calculations, the impact of ASE noise is governed by the wavelength dependence of the noise figure and the optical gain, and the degradation of SNR due to ASE noise becomes significant when the wavelength of the initial pulse is far from the gain peak. The detailed discussion on the relationship between ASE noise and the noise performance of similaritons will be presented elsewhere.

Another important difference is that the bandwidth of the similariton is limited by the gain bandwidth of NDFA. Needless to say, we should use the fiber amplifier which has the gain bandwidth broader than the similariton bandwidth. Recently proposed wideband amplifiers [14] may be useful for the broadband similariton generation.

If the limitation of the gain bandwidth is eliminated, the bandwidth of the similariton is determined by Eq. (12). Here, we rewrite the bandwidth $\Delta f$ of similariton in real units by using Eqs. (2)–(4) as

$$
\Delta f = \frac{1}{\pi} \left( \frac{g_0 E_{\text{in}}}{2p^2} \right)^{1/3} \exp \left( \frac{qL}{3} \right) = \frac{1}{\pi} \left( \frac{g_0 G_{\text{in}} \log C}{2p^2 L} \right)^{1/3}.
$$

From this equation, it is concluded that the use of an NDFA with smaller dispersion, higher nonlinearity, higher optical gain and short length is preferable for a broader spectrum. Moreover, from Eq. (16), input pulse width has to be reduced so as not to change the normalized pulse width.

In terms of the flatness of the broadened spectrum, the similariton is very attractive. Unlike the super-continuum (SC) generation in anomalous dispersion fibers without gain, the broadened spectrum of the similariton does not contain any residual pump component (except for the small oscillatory structure due to the satellite pulses), and the spectrum is very smooth. It should be mentioned that the similariton-based device is not the only way to generate such a flat spectrum. Actually, Ref. [15] discussed the reduction of the ripple of SC spectra from a dispersion-flattened, normal dispersion fiber by extending the fiber length numerically.

![Fig. 8](image-url)
From the viewpoint of practical applications, similariton-based sources have some advantages. First, the similariton has the immunity of the input pulse condition. As shown in Fig.5, the spectral width of the similariton calculated is almost the same for different pulse width ranging from 1 ps to 3 ps. This kind of immunity can never be seen in SC generation from optical fibers without gain. Moreover, the setup is more compact than that of the previous SPM-based devices because the booster amplifier and the nonlinear fiber are integrated in the similariton-based device.

6. Conclusion

We have investigated high repetition-rate similariton generation in optical communication systems. We introduced the normalized similariton solution, and then used it for the design of the similariton generation system. We showed that a km-long highly nonlinear fiber amplifier with a low normal dispersion can generate a high repetition-rate similariton train. In the experiment, we demonstrated a 10-GHz similariton source using the 1.2-km-long highly nonlinear EDF and evaluated the noise performance for the application to multi-wavelength sources. It was shown that the similariton source exhibited low-noise performance, which is attributed to the spectral flatness of the similariton.

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