Supercontinuum generation in silicon Bragg grating waveguide

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ABSTRACT

Supercontinuum generation is an extensively studied and arguably the most important and all-encompassing nonlinear phenomenon. Yet, we do not have a good control over all the signals generated in this process. Usually, a large part of an octave spanning spectrum has an orders of magnitude weaker signal than the peak to be useful for any application. In this work, we show strong signal generation within a supercontinuum generated in a complementary metal-oxide-semiconductor compatible silicon Bragg grating waveguide. We show up to 23 dB of signal enhancement over a 10 nm full-width-at-half-maximum bandwidth at the Bragg resonance in the telecom window. Additionally, the grating is made by depositing charge carriers periodically, thus avoiding any dimensional change in the waveguide, and it can allow other functionalities offered by the induced electric field, such as second harmonic generation and free carrier sweeping. We believe this work opens up an avenue for research in nonlinear integrated photonics and signal enhancement in the supercontinuum by the Bragg effect (whether created through grating formation with dimensional variation in insulators and/or periodic charge carrier doping in semiconductors).

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A classic example of nonlinear photonics is the supercontinuum (SC) generation that has been well studied in waveguides and fibers for many years. By launching high power pulses into a nonlinear medium in the anomalous dispersion regime, it is now a routine to achieve an octave spanning supercontinuum for a variety of applications. However, the supercontinuum can have weaker spectral windows that can span sometimes hundreds of nanometers.1–3 This is a problem for applications relying on the strength of the signals generated in a desired spectral window, such as optical frequency metrology, telecom/Datacom, and chemical-sensing applications.4–8 The supercontinuum spectrum has weak spectral windows for a given optical mode because the SC based on anomalous dispersion consists of dispersive waves and solitons that have fixed spectral locations determined by the dispersion profile of a waveguide defined by its cross section. By varying the cross section, thus the dispersion, along the length of a waveguide, one can achieve a much flatter SC by controlling the generation of the dispersive waves and the solitons, accordingly, along the length of a waveguide, thus providing some control over the wavelength of the nonlinearly generated signal as was shown in a silicon waveguide (with 250 fs and 100 W peak power of the pump pulse),9 and in a silicon nitride waveguide (with 60 fs and 3.7 kW peak power of the pump pulse).10 However, the SC enhancement based on such non-uniform cross section waveguides can still have weak spectral windows that can span over several nanometers, and, moreover, the wavelength of the dispersive waves, utilized in this technique, is dependent on the pump power. This limitation can become a problem for on-chip devices where the pump power tends to be limited.

To address the challenge of signal generation at desired spectral windows with sub-nm precision, an interesting approach is to modulate the group velocity dispersion and/or nonlinearity at the pump wavelength, for example, by periodically varying the waveguide width along the length of the waveguide, thus giving rise to higher order dispersive waves.11–13 However, this technique can be challenging in terms of flexibility in the spectral location and amplitude of the enhanced signal and also imposes fabrication challenges, for example, in a cladding modulated integrated waveguide.14

In this work, we demonstrate on-chip Bragg resonance-based signal enhancement that can potentially be used to generate signals in the
dark spectral windows of a supercontinuum. The technique relies on the weak-grating-based strong modulation of waveguide dispersion near the Bragg resonance, which can cover many nanometers for a grating having a bandwidth less than a 1 nm. Due to the precise control of the period of the grating, the Bragg resonance wavelength, this offers excellent control over the wavelength of the signal enhancement, virtually independent of the pump power and, hence, on-demand shaping of the spectrum anywhere in the supercontinuum, which has been utilized successfully so far only in optical fibers over a decade ago.\(^{15}\) In this work, we show more than 20 dB enhancement on-chip over 10 nm of bandwidth in the telecom window using the Bragg effect. Moreover, the grating is fabricated by depositing charge carriers periodically along the length of the waveguide, thus avoiding any dimensional change of the waveguide while also potentially offering other functionalities such as reducing the lifetime of the free carriers generated by the nonlinear absorption and second harmonic generation through external field induced electric poling.\(^{16,17}\) This work not only is useful for signal enhancement through the Bragg effect at wavelengths where dispersive waves are weak and can be applied to applications discussed above but also encourages future exploration of nonlinear optics in integrated Bragg grating waveguides that can very well be made of semiconductor or insulator medium.\(^{21-22}\)

We designed a waveguide with a width \(w\) of 800 nm, a height \(h\) of 380 nm, and a slab thickness \(s\) of 65 nm as shown in Fig. 1(b). The grating is of higher order to serve the dual purpose of ease in fabrication and periodic poling of silicon for second harmonic generation,\(^{16,17}\) which will be reported in the future work. The grating with 50% duty cycle was formed by doping the waveguide with \(n\)- and \(p\)-type species overlapping the slab and partly the strip section of the waveguide by 30 nm, as shown in Figs. 1(a) and 1(b). In a periodic structure like a Bragg grating, the incident or forward propagating wave experiences Fresnel reflection and coherently interferes at a wavelength determined by the periodicity of index variation, thus giving rise to an overall reflected Bragg signal.\(^{23-25}\)

The strength of the coupling of the forward wave to the backward reflected wave is defined by the grating coupling constant, given as

\[
k = \frac{\eta_{wg}}{\eta_{gr}}
\]

where \(\eta_{wg}\) is the index of the grating, \(\eta_{wg}\) is the modulation of the index of the grating, \(e\) is the overlap of the mode of the incident wave with the grating, \(m\) is the order (odd) of the grating, and \(\lambda_B\) is the Bragg wavelength, which is equal to \(2n_{tg}/m\), where \(n_{tg}\) is the average of the effective index of the mode at \(\lambda_B\) with and without grating and \(A\) is the grating period, which was designed to be 1650 nm.

The grating causes sharp variation in dispersion around the reflection wavelength, \(\lambda_B\), and is significantly stronger than the dispersion for the uniform waveguide due to the strong group delay introduced by the grating, which is discussed later (the dispersion curve was obtained by solving coupled mode equation for the grating response\(^{15}\) and calculating effective indices of the fundamental TE mode for the uniform waveguide using a mode solver).

The waveguide was fabricated in a standard 300-nm line complementary metal-oxide-semiconductor (CMOS) foundry (CNS SUNY polytechnic). To fabricate the grating, the dopants were ion implanted in the silicon layer to create \(p\)-type and \(n\)-type regions at a tilt angle of 20° to the normal of the wafer. In the experiment, the pump light at 1.95 \(\mu m\) was launched from an optical parametric oscillator (830 nm pump and 1450 nm signal generating idler around 1.95 \(\mu m\)) having a pulse width of 250 fs at a repetition rate of 80 MHz and was coupled into the waveguide with the peak power of 100–150 W using a free-space lens of numerical aperture ~0.6, and the output was measured with an optical spectrum analyzer connected to a ZBLAN fiber (Thorlab M11L2) butt-coupled to the waveguide. Since the grating was based on charge carriers, the propagation loss at the pump wavelength is expected to be 4–5 dB/cm.\(^{11}\) The supercontinuum generation, based on the soliton fission process,\(^{26-28}\) is shown in Fig. 2. Here, we see the grating-based signal enhancement of 23 dB with 10 nm of bandwidth at a full width at half maximum (FWHM) around the Bragg wavelength of 1230 nm. There is a slight variation between the two SC spectra due to the coupled pump power variation and the propagation loss difference. The spectrum was taken with the resolution of 0.5 nm. To demonstrate fine control on the grating-based signal enhancement, we fabricated gratings with the period varying in step size of 10 nm for which the measured supercontinuum is shown in Fig. 3. The enhanced signal is shifting 9 nm in wavelength for every 10 nm variation of the period of the higher order grating, thus illustrating a good control over the spectral location of the signal enhancement. The grating-enhanced signal is broad and strong in the regions where the supercontinuum is weak and becomes narrower as the signal starts overlapping the stronger regions of the supercontinuum (top plots of Fig. 3). The signal strength varies between 13 and 23 dB in the entire tested range with a respective bandwidth variation of 5–10 nm. The reduction in the strength of the grating-enhanced signal in the upper plots is most likely caused by the weaker nonlinear interaction in the gratings owing to lower pump powers caused by loss in the longer waveguides used before the gratings due to fabrication constraints. The rest of the spectrum, above 1420 nm, is not shown as it varies negligibly from Fig. 2(a). Also, we did not see any
changes in the response of the enhanced signal with the application of up to 5 V reverse bias. We note that the $k_B$ can be slightly different from the designed values due to the Kerr-based index change, and a weak optical parametric oscillator (OPO) signal ($1.45 \mu m$) was observed at the output, due to unavoidable leakage, which was subsequently filtered out.

To understand the underlying mechanism, we solved the nonlinear Schrödinger equation (NLSE) using the split step Fourier method. To account for the fast variation afforded by the grating on the waveguide dispersion, we used the full dispersion of the waveguide and employed spline interpolation to minimize the interpolation error while extracting the dispersion from the calculated effective index at discrete wavelengths. An NLSE, similar to $dE/dz = i(D_{w+g} + \gamma + i\alpha)E$, was solved to determine the signal enhancement. Here, $E$ is the pulse field envelope, $z$ is the propagation loss, and the dispersion term in the frequency domain is given as $D_{w+g} = \beta_{w+g}(\omega) = \beta_{w+g}(\omega_0) - (\omega - \omega_0) \beta_{1w+g}(\omega_0)$, where $\beta_{w+g}$ and $\beta_{1w+g}$ are the full dispersion and the first order derivative of the full dispersion of the grating waveguide and $\gamma$ is the intensity dependent nonlinear term that includes nonlinear index and loss terms and is given as $\gamma = (2\pi n_2/\lambda A_{eff} + i\beta_{non}(2\lambda A_{eff})(1 + i/\omega A_{eff})).$ In the simulation, we used a 250 fs pulse, with the peak power of 200 W, the waveguide length was 5 mm, the effective area of the pump mode was 0.3 $\mu m^2$, the Kerr factor was $12 \times 10^{-18} m^2/W$, and the propagation loss was 5 dB/cm. The simulated supercontinuum spectrum with- and without-grating is shown in Fig. 4.

In Fig. 4, we see that the signal strength at the Bragg wavelength, $\lambda_B$, of 1230 nm, as in Fig. 2, is enhanced by 20 dB over that of the without-grating waveguide and the rest of the spectrum remains fairly similar. The group velocity dispersion without the grating is $1.24 \times 10^{-24} s^2/m$ near 1230 nm (normal dispersion), and with the grating, the dispersion varies 4–5 orders of magnitude between normal and anomalous dispersion. Such a large grating-induced dispersion variation has been considered before for nonlinear pulse compression and dispersion compensation in optical fibers. This extreme dispersion variation causes the signal around the Bragg resonance to be generated through the Kerr effect.

In Figs. 5(a) and 5(b), we show how this grating-based dispersive wave is generated near the soliton fission point of roughly 2 mm. The signal gets strongly enhanced near the Bragg resonance in the grating waveguide and remains strong for the entire length of the waveguide. In the without-grating waveguide, the original broadband dispersive wave between 1150 and 1200 nm is generated. Although, we used a device of 5 mm length, a shorter device, slightly longer than 2 mm, can...
also generate an efficient supercontinuum as the overall spectrum does not change significantly beyond the soliton fission point as can be seen in Figs. 5(a) and 5(b). In Fig. 5(c), the phase matching of the dispersive wave to the soliton with and without the grating is shown where the presence of the grating allows the signal near the grating resonance (1.22 µm) to be phase matched to the soliton (for the calculation, an approximate dispersion was used to save computation time). In Fig. 5(d), we see the temporal profile of the pulse at the output of the waveguide. The grating-enhanced signal is lagging significantly behind the main pulse by several picoseconds because the grating adds extra group delay to these newly generated dispersive waves. The group delay introduced by the grating is shown in Fig. 5(d), where we see large spikes next to the reflection window, which slowly oscillate down to the group delay introduced by the waveguide without grating, which is 66 ps for a 5 mm long waveguide. These large oscillations in the group delay give rise to the rapidly varying normal and anomalous dispersion in the transmission region of the grating. The calculated transmission response of our grating and the group delay dispersion (GDD) is shown in Fig. 5(e). Here, the GDD oscillates between positive and negative values away from the resonance, which still imposes a strong variation of dispersion on the waveguide far away from the resonance. We must note here that a stronger grating will have high reflection, which can cause an adverse effect on the overall SC generation.

In conclusion, we have shown strong, grating-based signal enhancement of more than 20 dB over a bandwidth of 10 nm (FWHM) in the supercontinuum generated in a silicon waveguide. Since the grating is based on charge-carrier induced index variation, the device can also be used for electrically poled second harmonic generation. Moreover, as this technique can give precise control over the wavelength of the enhanced signal and, therefore, help fill the spectral gaps present in a supercontinuum with precision defined by the grating period that can be within nanometers, it has been used (with highly nonlinear fiber) to stabilize the carrier envelope offset frequency of a modelocked laser. The grating-enhanced signal is normally dispersed in time and can be compressed with an additional waveguide and, if required, be further enhanced by cross phase modulation. We believe that, together with dispersive wave generation, the grating signal enhancement technique can allow efficient supercontinuum generation in integrated nonlinear photonics.

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**DATA AVAILABILITY**

The data that support the findings of this study are available from the corresponding author upon reasonable request.

**REFERENCES**

1. J. M. Dudley, G. Genty, and S. Coen, “Supercontinuum generation in photonic crystal fiber,” Rev. Mod. Phys. 78, 1135 (2006).
2. G. Agrawal, *Nonlinear Fiber Optics*, 5th ed. (Elsevier, Amsterdam, 2012).
3. D. Castello-Lurbe, N. Vermeulen, and E. Silvestre, “Towards an analytical framework for tailoring supercontinuum generation,” Opt. Express 24(23), 26628–26645 (2016).
4. H. R. Telle, G. Steinmeyer, A. E. Dunlop, J. Stenger, D. H. Sutter, and U. Keller, “Carrier-envelope offset phase control: A novel concept for absolute optical frequency measurement and ultrafast pulse generation,” Appl. Phys. B 69, 327–332 (1999).
5. F. Morini, K. Mori, and M. Saruwatari, “More than 100-wavelength-channel picosecond optical pulse generation from single laser source using supercontinuum in optical fibres,” Electron. Lett. 29(10), 862–864 (1993).
6. D. T. Spencer, T. Drake, T. C. Briles, J. Stone, L. C. Sinclair, C. Fredrick, Q. Li, D. Westly, B. R. Ilic, A. Bluestone et al., “An optical-frequency synthesizer using integrated photonics,” Nature 557(7703), 81–85 (2018).
7. N. Singh, M. Xin, N. Li, D. Vermeulen, A. Ruocco, E. S. Magden, K. Shytirova, E. Ippen, F. X. Kaertner, and M. R. Watts, “Silicon photonics optical frequency synthesizer,” Laser Photonics Rev. 14, 1900449 (2020).
8. Q. Du, Z. Luo, H. Zhong, Y. Zhang, Y. Huang, T. Du, W. Zhang, T. Gu, and J. Hu, “Chip scale broadband spectroscopic chemical sensing using integrated supercontinuum source in a chalcogenide glass waveguide,” Photonics Res. 6, 506–510 (2018).
9. N. Singh, D. Vermeulen, A. Ruocco, N. Li, E. Ippen, F. X. Kartner, and M. R. Watts, “Supercontinuum generation in varying-dispersion and birefringent silicon waveguide,” Opt. Express 27(22), 31698–31712 (2019).
10. D. R. Carlson, P. Hutchison, D. D. Hickstein, and S. B. Papp, “Generating few-cycle pulses with integrated nonlinear photonics,” Opt. Express 27(26), 37374–37382 (2019).
11. M. Conforti, S. Trillo, A. Mussot, and A. Kudlinski, “Parametric excitation of multiple resonant radiation from localized wavepackets,” Sci. Rep. 5, 9433 (2015).
12. F. P. Gordon, “Dispersive perturbation of solitons of the nonlinear Schrödinger equation,” J. Opt. Soc. Am. 9, 91–97 (1922).
13 S. M. Kelly, “Characteristic sideband instability of periodically amplified average soliton,” Electron. Lett. 28, 1562 (1992).

14 D. D. Hickstein, G. C. Kerber, D. R. Carlson, L. Chang, D. Westly, K. Srinivasan, A. Kowligy, J. E. Bowers, S. A. Diddams, and S. B. Papp, “Quasi-phase-matched supercontinuum generation in photonic waveguides,” Phys. Rev. Lett. 120, 053903 (2018).

15 P. S. Westbrook, J. W. Nicholson, K. S. Feder, Y. Li, and T. Brown, “Supercontinuum generation in a fiber grating,” Appl. Phys. Lett. 85(20), 4600–4602 (2004).

16 E. Timurdogan, C. V. Poulton, M. J. Byrd, and M. R. Watts, “Electric field-induced second order nonlinear optical effects in silicon waveguides,” Nat. Photonics 11, 200–206 (2017).

17 N. Singh, M. Raval, A. Ruocco, and M. R. Watts, “Broadband 200-nm second harmonic generation in silicon in the telecom band,” Light Sci. Appl. 6, e17210 (2017).

18 A. Billat, D. Grassani, M. H. P. Pfeiffer, S. Kharitonov, T. J. Kippenberg, and C. S. Bres, “Large second harmonic generation enhancement in Si3N4 waveguides by all-optically induced quasi phase matching,” Nat. Commun. 8(1), 1–7 (2017).

19 M. Yu, B. Desiatov, Y. Okawachi, A. L. Gaeta, and M. Loncar, “Coherent two octave spanning supercontinuum generation in lithium niobate waveguides,” Opt. Express 23(12), 15440–15451 (2015).

20 A. S. Mayer, A. Klenner, A. R. Johnson, K. Luke, M. R. E. Lamont, Y. Okawachi, M. Lipson, A. L. Gaeta, and U. Keller, “Frequency comb offset detection using supercontinuum generation in silicon nitride waveguides,” Opt. Express 23(12), 15440–15451 (2015).

21 N. Singh, H. M. Mbonde, H. C. Frankis, E. Ippen, J. D. B. Bradley, and F. X. Kartner, “Nonlinear silicon photonics on CMOS-compatible tellurium oxide,” Photonics Res. 8(12), 1904–1909 (2020).

22 U. D. Dave, C. Ciret, S. P. Gorza, S. Combrise, A. D. Rossi, F. Raineri, G. Roelkens, and B. Kuyken, “Dispersive wave based octave spanning supercontinuum generation in InGaP membrane waveguides on a silicon substrate,” Opt. Lett. 40(15), 3584–3587 (2015).

23 H. Kogelnik and C. V. Shank, “Coupled-wave theory of distributed feedback laser,” J. Appl. Phys. 43, 2327–2335 (1972).

24 T. Erdogan, “Fiber grating spectra,” J. Light. Technol. 15, 1277–1294 (1997).

25 J. Buus, M. C. Amann, and D. J. Blumenthal, Tunable Laser Diodes and Related Optical Sources, 2nd ed. (Wiles-IEEE Press, 2005).

26 A. Soref and B. R. Bennett, “Electrooptical effects in silicon,” IEEE J. Quantum Elect. 23, 123–129 (1987).

27 Y. Li, F. C. Salisbury, Z. Zhu, T. G. Brown, P. S. Westbrook, K. S. Feder, and R. S. Windeler, “Interaction of supercontinuum and Raman solitons with microstructure fiber gratings,” Opt. Express 13(3), 998–1007 (2005).

28 P. E. Murphy, “Design, fabrication and measurement of integrated Bragg grating optical filters,” Ph.D. dissertation (Massachusetts Institute of Technology, Cambridge, MA, 2001).

29 J. Leuthold, C. Koos, and W. Freude, “Nonlinear silicon photonics,” Nat. Photonics 4, 535–544 (2010).

30 N. Singh, M. Xin, D. Vermeulen, K. ShtrYkova, N. Li, P. T. Callahan, E. S. Magden, A. Ruocco, N. Fahrenkopf, C. Baiocco et al., “Octave-spanning coherent supercontinuum generation in silicon on insulator from 1.06 μm to beyond 2.4 μm,” Light: Sci. Appl. 7, 1–8 (2018).

31 R. Halir, Y. Okawachi, J. S. Levy, M. A. Foster, M. Lipson, and A. L. Gaeta, “Ultrafast broad continuum generation in a CMOS-compatible platform,” Opt. Lett. 37, 1685–1687 (2012).

32 D. D. Hickstein, H. Jung, D. R. Carlson, A. Lind, I. Coddington, K. Srinivasan, G. G. Ycas, D. C. Cole, A. Kowligy, C. Fredrick, S. Droste, E. S. Lamb, N. R. Newbury, H. X. Tang, S. A. Diddams, and S. B. Papp, “Ultrafast broad continuum generation and frequency-comb stabilization using on-chip waveguides with both cubic and quadratic nonlinearities,” Phys. Rev. Appl. 8, 014025 (2017).

33 Y. Yu, X. Gai, P. Ma, D. Y. Choi, Z. Yang, R. Wang, S. Debbia, S. J. Madden, and B. L. Davies, “A broadband, quasi-continuous, mid-infrared supercontinuum generated in a chalcogenide glass waveguide,” Laser Photonics Rev. 8, 792–798 (2014).

34 C. R. Philips, C. Langrock, J. S. Pels, M. M. Fejer, J. Jiang, M. E. Fermann, and I. Hartl, “Supercontinuum generation in quasi-phase-matched LiNbO3 waveguide pumped by a Tm-doped fiber laser system,” Opt. Lett. 36, 3912–3914 (2011).

35 B. Kuyken, X. P. Liu, R. M. Osgood, R. Baets, G. Roelkens, and W. M. J. Green, “Mid-infrared to telecom-band supercontinuum generation in highly nonlinear silicon-on-insulator wire waveguides,” Opt. Express 19, 20172–20181 (2011).

36 Y. Yin, Q. Lin, and G. P. Agrawal, “Soliton fission and supercontinuum generation in silicon waveguides,” Opt. Lett. 32, 391 (2007).

37 B. J. Eggleton, T. Stephens, P. A. Krug, G. Dhosi, Z. Brodzel, and F. Ouellette, “Dispersion compensation using fibre grating in transmission,” Electron Lett. 32, 1610–1611 (1996).

38 C. M. de Sterke, “Optical push broom,” Opt. Lett. 17, 914–916 (1992).

39 H. G. Winful, “Pulse compression in optical fiber filters,” Appl. Phys. Lett. 46, 527 (1985).

40 P. S. Westbrook and J. W. Nicholson, “Perturbative approach to continuum generation in a fiber Bragg grating,” Opt. Express 14, 7610 (2006).

41 P. S. Westbrook, J. W. Nicholson, and K. S. Feder, “Grating phase matching beyond a continuum edge,” Opt. Lett. 32(17), 2629–2631 (2007).

42 D. R. Austin, J. A. Bolger, C. M. de Sterke, B. J. Eggleton, and T. G. Brown, “Narrowband supercontinuum control using phase shaping,” Opt. Express 14(26), 13142–13150 (2006).

43 K. Kim, S. A. Diddams, P. S. Westbrook, J. W. Nicholson, and K. S. Feder, “Improved stabilization of a 1.3 μm femtosecond optical frequency comb by use of a spectrally tailored continuum from a nonlinear fiber grating,” Opt. Lett. 31, 277–279 (2006).