channel spacing frequency, where the input pump power is 12 dBm. The output power of the present fiber decreased more rapidly than that of a conventional DSF as the channel spacing increased. This is probably because the chromatic dispersion of the present fiber is less uniform than that of conventional DSF. However, when the channel spacing was <200 GHz, the output power of the present fiber was much higher than that of a conventional DSF.

In conclusion, we have described a tapered core fiber with uniform chromatic dispersion along its length. High FWM efficiency was obtained when the input power was the same as the SBS threshold power (12 dBm). This fiber is useful for wavelength conversion.

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TuN7 **6:15pm**

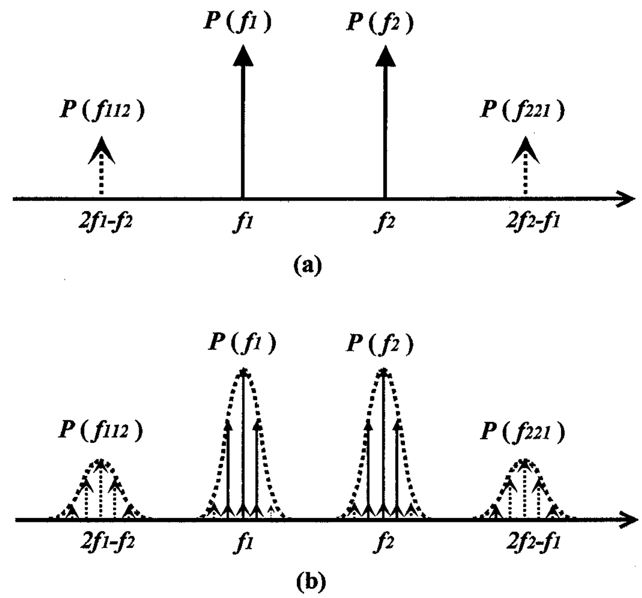
Four-wave mixing of spectrum-sliced fiber amplifier light source in a dispersion-shifted fiber

Y.S. Jang, Y.C. Chung, *Korea Advanced Institute of Science and Technology, Department of Electrical Engineering, 373-1 Kusong-dong, Yusong-gu, Taejon 305-701, Korea*

Four-wave mixing (FWM) is one of the most important nonlinear processes that may limit the capacity of wavelength-division multiplexing (WDM) systems. The impact of the FWM in a system using coherent light sources such as lasers has been studied extensively.[1–3] Recently, we proposed a spectrum-sliced fiber amplifier light source for the use in WDM systems.[4] Unlike the laser sources, these potentially inexpensive WDM sources are incoherent and broadband. In this paper, we report the FWM of incoherent light sources, to our knowledge, for the first time. The results are compared with coherent laser sources.

Figure 1(a) shows that FWM process generates two additional signals when two coherent input signals are launched into a fiber. However, FWM of incoherent lights would result in a different optical spectrum as shown in Fig. 1(b). This is because the incoherent input signal is composed of numerous independent frequency components. Thus, FWM process could generate numerous additional frequency components both within and outside of the input signal bandwidth. Those FWM signals outside of the input signal bandwidth may degrade the system's performance via cross talk. Thus, the FWM power of incoherent light sources, $P(f_{112})$, is defined as the total power within the bandwidth of the FWM signal at frequency $(2f_1 - f_2)$.

Theoretically, incoherent light could be defined as a sum of numerous independent frequency components, in which the complex envelope of each frequency component is described by circular complex Gaussian random variable.[5] In addition, the state of polarization of each frequency component is random. However, we assume linearly polarized incoherent lights to make comparison with coherent laser sources. Thus, the FWM power, $P_1(l)$, generated by three incoherent signals can be described as (in MKS units)

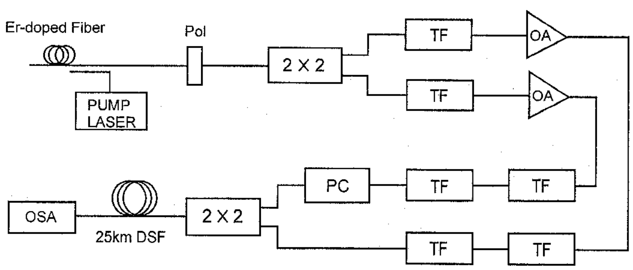


TuN7 Fig. 1. Optical spectrum at the output of optical fiber. (a) FWM signals generated by two coherent input signals and (b) FWM signals generated by two incoherent input signals which are composed of numerous independent frequency components.

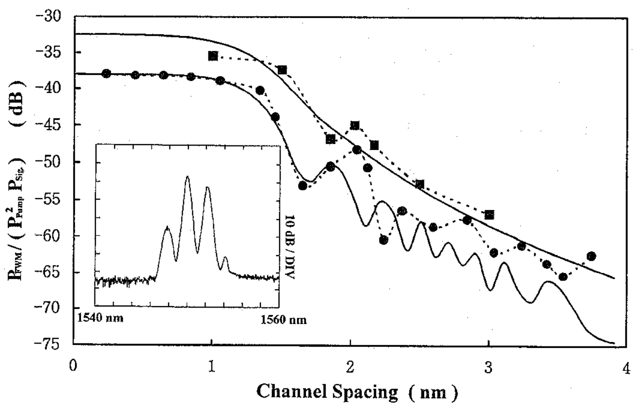
$$P_1(l) = \int \frac{4\eta_0^2\pi^2 f_1^2}{n^4 c^2}(d\chi_{xxxx})^2 \frac{l_{eff}^2}{A_{eff}^2} e^{-\alpha l} \iint \eta(\Delta\beta)\, P_2(f_2)\, P_3(f_3)\, P_4(f_4)\, df_2\, df_3\, df_1$$

where η_0 is the intrinsic impedance of free space, n is the refractive index of fiber core, c is the speed of light, d is the degeneracy factor, χ_{xxxx} is the third-order nonlinear coefficient, A_{eff} is the effective core area, l_{eff} is the effective fiber length, l is the fiber length, α is the fiber loss coefficient, $\eta(\Delta\beta)$ is the FWM efficiency, $\Delta\beta$ is the phase-mismatch, $P_i(f_i)$ are launched signal powers at frequency f_i (i = 2, 3, and 4). The FWM signal is composed of many frequency components at $f_1 (= f_2 + f_3 - f_4)$. Using this equation, we calculated the FWM signal power of incoherent sources. For our calculation, we used the following parameters are: α = 0.21 dB/km, $dD/d\lambda$ = 0.07 ps/km.nm^2, and the zero-dispersion wavelength, λ_0 = 1.550 μm. The nonlinear term, $4\eta_0^2\pi^2\chi_{xxxx}^2/n^4c^2A_{eff}^2$ = 7.5×10^{-36} ($s^2m^{-2}W^{-2}$), was obtained experimentally. The results show that, when only two input signals are launched into the fiber, the FWM of incoherent sources is 5.4 dB more efficient than that of coherent sources. This is because the degeneracy factor is $d = 3$ when two coherent input signals are used, while incoherent lights generated FWM signals mostly by the nondegenerate ($d = 6$) FWM process.

The experimental setup is shown in Fig. 2. The amplified spontaneous emission (ASE) from a backward-pumped erbium-doped fiber amplifier was spectrum-sliced using bandpass filters. The ASE light was then amplified and filtered again to produce high power input signals with narrow bandwidth. Both channels had 3-dB bandwidth of about 0.45 nm. The polarization states of both input signals were adjusted to be same using an optical polarizer and a polarization controller. These incoherent signals were launched into a 25-km-long dispersion-shifted fiber. Probe channel was always set to operate at the dispersion-zero



TuN7 **Fig. 2.** Experimental setup. Pol: polarizer, PC: polarization controller, TF: tunable filter, OA: optical amplifier.



TuN7 **Fig. 3.** FWM efficiencies of incoherent light sources in comparison with coherent light sources. The solid lines are theoretically calculated curves. ■ represents the measured data for incoherent sources and ● represents the measured data for coherent sources. In this measurement, the signal channel was set at the dispersion-zero wavelength at 1.55 μm. The pump and signal powers were 0 dBm and 5 dBm, respectively. The inset shows an optical spectrum measured at the output of dispersion-shifted fiber with two incoherent input signals.

wavelength while the wavelength of pump channel was varied. The FWM power was measured using an optical spectrum analyzer and an optical power meter. The same experiment was repeated with two external cavity tunable lasers to make a comparison with coherent light sources.

Figure 3 shows the measured FWM power of coherent and incoherent light sources in comparison with theoretically calculated curves. The FWM power is normalized by the input signal powers, $P_1{}^2P_2$. The results for the laser sources show good agreement with other papers.[2,3] When two input signals were used, the incoherent light sources generate about 5 dB higher FWM efficiency than coherent sources. However, the FWM efficiency of the incoherent light source was similar to the coherent sources if three input signals were used, as expected. We also found that the bandwidth of an incoherent light becomes slightly broader after traversing the fiber due to FWM, even when only one light was launched into fiber. These results confirm that the incoherent light could be modeled as sum of numerous independent frequency components.

In summary, we investigated the FWM of incoherent lights in a dispersion-shifted fiber. The results show that, when two input signals were used, the FWM of incoherent sources is about 5 dB more efficient than that of coherent sources due to the degeneracy factor.

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TuO

4:30–6:30pm

Ballroom C2

Wavelength Conversion

Katherine Hall, *MIT Lincoln Laboratory, Presider*

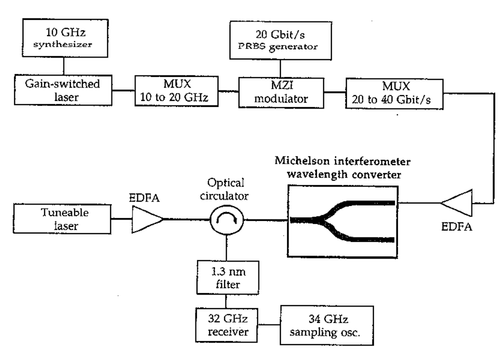
TuO1 **4:30pm**

All-optical 40-Gbit/s compact integrated interferometric wavelength converter

C. Joergensen, S.L. Danielsen, P.B. Hansen, K.E. Stubkjaer, M. Schilling,* K. Daub,* E. Lach,* G. Laube,* W. Idler,* K. Wunstel,* *Center for Broadband Telecommunications, Department of Electromagnetic Systems, Technical University of Denmark, Building 348, DK-2800 Lyngby, Denmark; E-mail: cj@emi.dtu.dk*

Some of the most practical all-optical wavelength-conversion devices reported in the literature exploit the cross-gain (XGM) or cross-phase (XPM) modulation concept using semiconductor optical amplifiers (SOAs) alone or SOAs integrated into interferometric structures.[1–5] Recently, 40 Gbit/s wavelength conversion using the very simple XGM principle in a speed-optimized SOA was demonstrated[3] verifying the potentially high-speed operation associated with the relatively simple interband carrier recombination process. Here, an interferometric Michelson wavelength converter is presented that combines a speed-optimized SOA technology with the benefits of the integrated interferometer showing 40-Gbit/s wavelength conversion for the first time to our knowledge. The optimized wavelength converter demonstrates noninverted converted signals as well as converts to both shorter and longer wavelengths. Excellent results are achieved with ~10 dB extinction ratio and more than 25 dB signal-to-ASE (amplified spontaneous emission) ratio (1 nm) for the converted signals at 40 Gbit/s.

The monolithic integrated Michelson interferometer (MI) chip is realized using all-active multiple quantum well (MQW) based layer



TuO1 **Fig. 1.** Experimental setup for investigation of the wavelength conversion performance of the Michelson interferometer at 40 Gbit/s.