GUIDED WAVES

the second harmonic field into the fundamental. The coupling is then strong enough to produce soliton-like beams mutually trapped.

"Solitary-wave-locking," we believe, will have a tremendous impact in the future design of second harmonic generators and tunable optical parametric sources, improving their stability and overall optical beam quality. In addition, it represents an invaluable testbed for the investigation of ultrafast multidimensional solitary wave physics.

Acknowledgments

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COMMUNICATIONS

Transmission of Eight 20 Gb/sec Channels over 232 km of Conventional Single-Mode Fiber

A. H. Gnauck, A. R. Chraplyvy, Fabrizio Forghieri, R. W. Tkach, R. M. Derosier, A. M. Vengsarkar, D. W. Peckham, J. L. Zyskind, and J. W. Sulhoff, AT&T Bell Laboratories, Holmdel, N.J.

Installed telecommunication lightwave systems are now being upgraded with erbium-doped-fiber-amplifier (EDFA) optical repeaters. Less expensive than full regenerators which receive, reshape, and re-transmit the optical signal, the EDFAs also allow future capacity increases through the use of wavelength-division multiplexing. These amplifiers operate at approximately 1555 nm, where the loss of conventional step-index fiber, used in almost all installed systems, is a low 0.2 dB/km. However, the fiber exhibits dispersion of 17 psec/nm•km at this wavelength. This restricts the transmission distance that can be reached before a signal must be regenerated to avoid incurring an unacceptable penalty from dispersion-induced distortion. For a transform-limited signal, the distance at which a 1 dB penalty is reached is inversely proportional to the square of the bit-rate—about 1000 km at 2.5 Gb/sec, 65 km at 10 Gb/sec, and 16 km at 20 Gb/sec.[1]

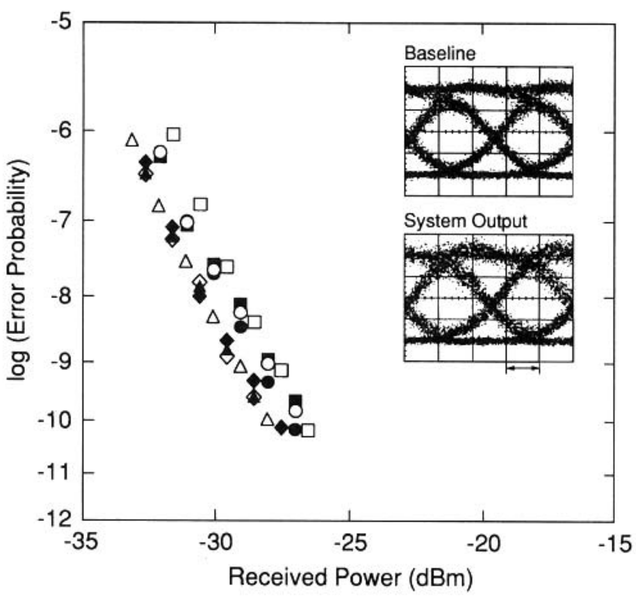

Figure 1. Bit-error-rate data for all eight channels after 232 km. Inset shows eye pattern at system input and output.

Laboratory and field demonstrations of upgrades have therefore followed two paths. Wavelength multiplexing of several 2.5 Gb/sec channels[2] has allowed unregenerated spans of hundreds of kilometers. Alternatively, higher bit-rate systems have been realized using shorter regenerator spacings or dispersion compensation. Recently[3] 10 Gb/sec transmission over 360 km of conventional fiber was achieved in a field trial using dispersion-compensating fiber (DCF). In this paper, we demonstrate that the strategy of dispersion compensation at a bit rate of 20 Gb/sec can be combined with extensive wavelength multiplexing. Eight 20 Gb/sec channels, spaced 200 GHz (1.6 nm) apart and centered around 1555 nm, have been transmitted over 232 km of conventional single-mode fiber. In addition to having negative chromatic dispersion of up to 100 psec/nm•km, the dispersion-compensating fiber used in this experiment,[4] also exhibits a negative dispersion slope. This partially compensates for the dispersion slope of the transmission fiber, resulting in an effective dispersion slope for the 232 km span of 0.02 psec/nm^2•km, compared to 0.08 psec/nm^2•km for the conventional fiber itself. This allows penalty-free transmission at 20 Gb/sec over the entire 11.2 nm bandwidth of the system.

The transmitter consists of eight external-cavity lasers combined in a star coupler and modulated with a $2^{31}-1$ pseudorandom bitstream by a Mach-Zehnder $LiNbO_3$ modulator. The channel powers are adjusted to obtain reasonably uniform signal-to-noise ratios at the receiver. The transmission line consists of three, 80-km spans of conventional step-index fiber, separated by two dispersion-compensating amplifier sites. These amplifier sites contain an ytterbium co-doped EDFA, DCF to compensate 80 km of fiber, and a 980 nm pumped EDFA which boosts the signals for the succeeding span. Additional dispersion compensation is provided at either end of the transmission line. The receiver consists of a 1480 nm pumped EDFA preamplifier, a tuneable 0.8 nm bandpass optical filter, and a commercial optical-to-electrical converter. Figure 1 (page 24) shows the bit-error-rate curves for all eight channels after 232 km transmission. All channels were received without discernible penalties and with no evidence of error-rate floors. The inset shows the transmitted and received 20 Gb/sec eye pattern for one of the channels.

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Multiple Colliding Pulse Mode-Locked Quantum Well Lasers

Joaquim F. Martins-Filho and Charles N. Ironside,
University of Glasgow, Glasgow, Scotland, U.K.

The future demand for broadband services is expected to require telecommunication networks to operate with terabit capacity.[1, 2] The realization of such high capacity networks requires flexible use of time, wavelength, and space switching.[1, 2] High-speed short pulse generation for high bit-rate time-division multiplexing (TDM) systems can be provided by monolithic mode-locked quantum well lasers for example, at repetition rates above 100 GHz, to be used in solitonic optical fiber transmission systems.[1, 2] Semiconductor laser mode-locking at harmonics of the cavity round trip frequency allows the generation of a very high repetition rate train of pulses from longer cavities. We present a multiple colliding pulse mode-locked (MCPM) laser configuration, that can generate one, two, three, or four pulses in the cavity, giving first (fundamental) to fourth harmonics of the repetition rate.[3, 4] The laser is an extension of the normal colliding pulse passively mode-locked laser, which consists of a gain section with one saturable absorber placed in the center of the cavity. The MCPM laser is flexible in the sense that its operation can be switched between one, two, three, or four pulses depending on the bias (forward or reverse) applied to each of its three independent sections (see Fig. 1), which changes the position and number of saturable absorbers in the cavity. Up to 375 GHz repetition rate has been achieved with a 400 μm long MCPM laser.[4] Pulses as short as approximately 1 psec have been obtained.

These monolithic mode-locked semiconductor laser devices offer the possibility of very low-cost, compact, reliable, robust, efficient sources of ultrashort pulses that can be mass-produced. The fabrication technology is basically the same as for compact disc lasers. This opens up potential application such areas as ultrafast data processing, optical-clock distribution for computing, opto-microwave-electronic interfacing, electro-

Figure 1

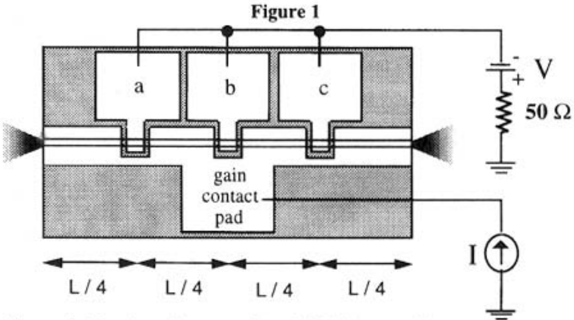

Figure 1. Top view diagram of the MCPM laser, with electrical connections.

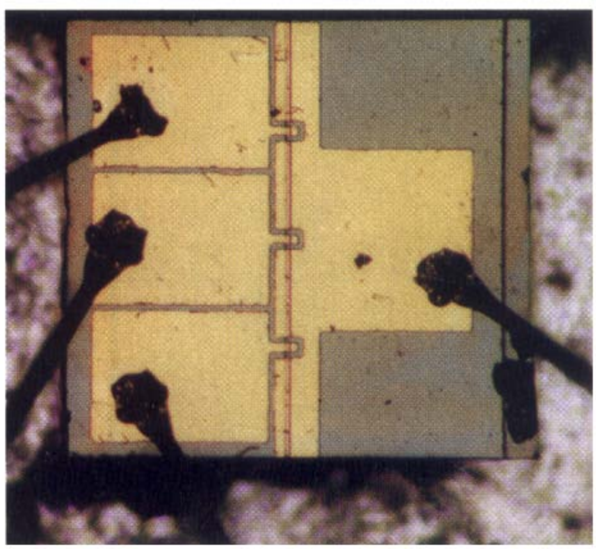

Photo 1. Top view diagram of a mounted and wire bonded MCPM laser. Laser dimensions are 600 μm by 600 μm.