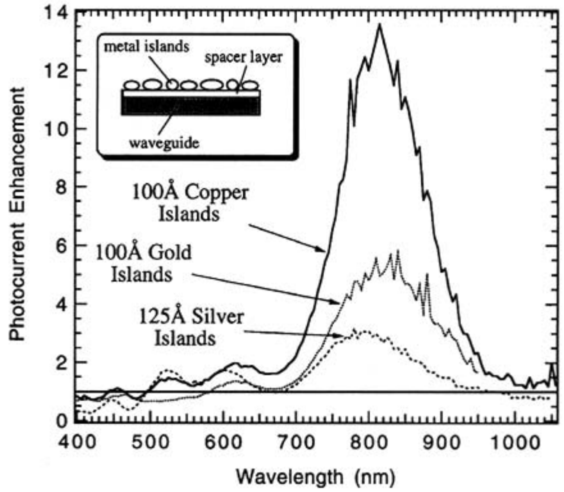

Figure 1. Examples of measured enhancements due to the presence of the metal island layer. Enhancement is defined as the ratio of the photocurrent of the device with the islands to that without the islands. The LiF thickness is 300Å for all curves. The inset shows the experimental geometry: The device is illuminated at normal incidence from above the island layer.

ble. That the enhancement increases dramatically as the bare island resonance moves to longer wavelengths (Ag to Au to Cu) supports strongly that the enhancement arises because of the island-mode coupling.

The observed effect can likely be implemented in other materials and at other wavelengths, and be used whenever coupling light more efficiently into a thin layer is required.

Acknowledgments

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SOLITONS

The Linear Perspective to Soliton Dynamics

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Unlike linear waves, solitons create their own channel as they travel in a uniform medium, remaining localized and preserving their shape.[1] Whereas linear waves always pass through one another, solitons can be dramatically altered by collisions. They can annihilate one another, fuse, or create multiple solitons.[2] These phenomena turn out to be important to the emerging technology of light guiding light and light written circuitry.[3-4] To pursue this technology, we need to understand how such waves interact in an arbitrary nonlinear medium.

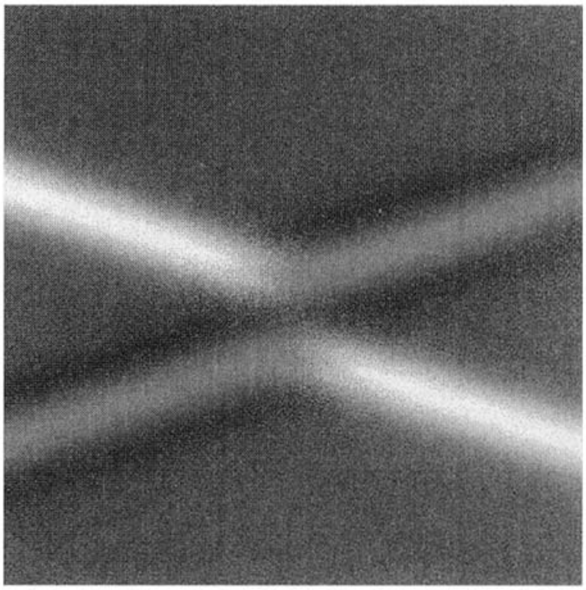

Figure 1. Light written circuitry. Waveguide coupler (white) induced by repelling solitons whose trajectory is described by linear theory.[4] A signal beam (grey) launched at the lower left port is transferred to the upper left port as is described by the standard coupled mode theory for linear couplers. (A color version of this image is on page 8.)

Traditionally, the subject is presented through the abstruse mathematics of the inverse scattering technique. This technique does not impart physical insight and it is restricted to one-dimensional solitons in a cubic (Kerr) medium. Solitons, in this special case, behave like linear waves in that they are unaltered by collisions,[4] apart from a translation in position.

But, solitons can be approached in a physically meaningful way and, surprisingly, from the familiar perspective of linear guided waves.[4] This applies to any nonlinear medium, including a $\chi^{(2)}$ medium or photorefractive medium. Conceptually speaking, nonlinear beams interact with matter to create their own waveguides. We emphasize that these waveguides are linear and that they can be of arbitrary shape and form. Beams then propagate along their own induced waveguide according to the familiar physics of linear optics. For example, in the simplest case a soliton is one mode of the waveguide it induces; more generally, it is any two modes of the induced waveguide which explains the coexistence of different classes of solitons such as dark and bright. Vector solitons are the exceptional case when the modes are degenerate. Periodic (higher order) solitons are simply created by the beating of modes, and so on. This significantly generalizes the soliton as originally[1] envisaged and provides the first physical explanation for mysterious phenomena such as radiation free collisions and periodic oscillations that result from scaling up a soliton.

The fact that every nonlinear problem has a linear equivalent provides a powerful conceptual tool, one that guides us in a physical manner to the fundamental equations and to their solutions, as well as providing us the insight necessary for predictions and for interpreting experiments.

The linear perspective[4] predicted vortex solitons, dynamic solitons, periodic solitons of non-Kerr material, and the fact that solitons can spiral about each other. It shows how light can guide or steer light. It motivates light written circuitry as shown in Figure 1 and it foreshadows the design of lossless waveguide components such as the "X" junction. It shows how to describe the interaction of solitons in 3-D and in non-Kerr law material. It predicts when colliding solitons will fuse or generate multiple solitons.[2, 4] It shows how the mathematical foundation of nonlinear waves is borrowed in an elegant form from linear waves. It allows for closed form solutions to be borrowed from the pages of linear physics. It provides a qualitative theory for the existence and stability of solitons.[5]

Acknowledgment

We are part of the Australian Photonics Cooperative Research Centre. F. Ladouceur provided Figure 1.

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Massive Soliton WDM Transmission at N × 10 Gbit/sec, Error-free Over Transoceanic Distances

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We have demonstrated massive wavelength division multiplexing (WDM), over transoceanic distances, in multiples of 10 Gbit/sec.[1] The vital ingredients to this success were first, solitons, second, sliding-frequency guiding filters, and third, the use of "dispersion-tapered" fiber spans between amplifiers, *i.e.*, spans for which $D(z)$ tends to follow (here in step-wise approximation), the same exponential decay profile as the signal energy. Although the first two ingredients and their benefits are by now well known,[2-4] the third, at least in this context, is both novel and vital. As we have detailed elsewhere,[5] first, without dispersion tapering, pseudo-phase matching allows four-wave mixing products from soliton-soliton collisions to grow uncontrollably, and hence to cause intolerable timing and amplitude jitter. Second, dispersion tapering lifts the restriction $L_{coll} \geq 2L_{amp}$ that obtains with spans of constant D,[6] which in turn limits the maximum allowable channel spacing. (L_{coll} and L_{amp} are the collision length and spacing between amplifiers, respectively.).

Figure 1 plots the measured error-free distances versus the number, N, of 10 Gbit/sec channels. For each of these points, the measured bit-error-rate (BER) was better than 1×10^{-9} on all N channels. We also performed an experiment at 5 Gbit/sec per channel (six channels), where the time-acceptance window could be opened up by a factor of two, and the rate of collisions was decreased by the same factor. For that experiment, the error-free distance was greater than 40 Mm.

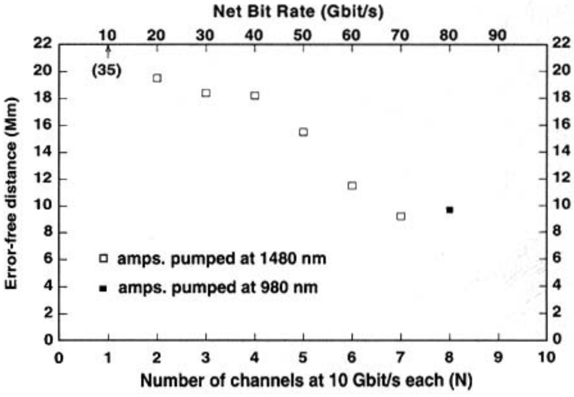

Figure 1. Achieved error-free distances versus the number of channels at 10 Gbit/sec each. For reference, the undersea trans Pacific cable distance is 9 Mm, and 20 Mm represents half the circumference of the Earth.

In "linear" transmission (often called "NRZ," for its non-return-to-zero format), adjusting the relative amplifier gains for the various WDM channels poses a formidable problem. In soliton transmission using guiding filters, however, pulses in those channels with higher net amplifier gains tend to increase in bandwidth until the filter loss exactly compensates for the excess gain. This phenomenon serves as a highly effective net gain control to stabilize the relative energies of the channels against variations in amplifier gain with wavelength.

Indeed, in our experiments, the strengths of the various channels quickly become locked to values that do not change with increasing distance, no matter how far.[1]

The $N \times 10$ Gbit/sec soliton WDM transmission represents the most practical and flexible way to achieve net bit rates of 100 Gbit/sec or greater. On the one hand, to attempt to put even half that capacity all into a single wavelength channel involves formidable difficulties, both fundamental and technical. With the WDM per-channel rate set at the 10 Gbit/sec SONET standard, however, further division (down to the finest degree of granularity that may be desired) is accomplished easily and flexibly in the time domain with existing and well-established technologies—both optical and electronic. With data that is immediately readable or injectable at any point along the path, and with the RZ (return-to-zero) format that is required for all-optical switching, the $N \times 10$ Gbit/sec soliton WDM is optimal for networking. By contrast, for WDM in "linear" ("NRZ") transmission, the requirement for lumped dispersion compensation, specific to each distance and to each wavelength, mitigates strongly against such networking.