CLEO '94
797

Unlimited soliton propagation and noise suppression in a system with spectral filtering and saturable absorption

V. V. Afanasjev[†], W. H. Loh, A. B. Grudinin, D. Atkinson[‡], and D. N.Payne

Optoelectronics Research Centre, Southampton University
Southampton S09 5NH, UK

[†] - Russian Academy of Sciences, General Physics Institute
38 Vavilov Stree, 117942 Moscow, Russia

[‡] - Optoelectronics Research Centre, Department of Electronic and Electrical Ingeeniring, University College London,
Torrington Place, London, WC1E 7JE, UK

Abstract

We show that soliton propagation is ultimately stable to both amplitude and frequency noise in a system employing spectral filtering and saturable absorption. In such a system, the amplification period may be increased to 3-5 dispersion lengths for 10 dB linear losses between amplifiers.

CThM6 3:45 pm

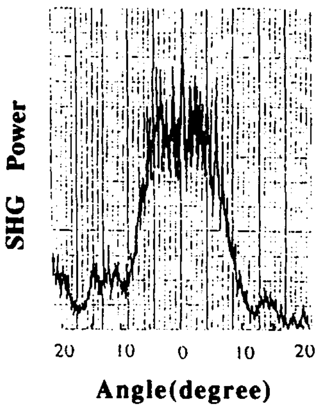
Growth of potassium lithium niobate fiber crystal and its application for blue light generation

Takahiro Obana, Masashi Yoshimura, Yusuke Mori, Takatomo Sasaki, Norio Ohnishi,* Tsuguo Fukuda,** Hiroyuki Tanaka,† *Department of Electrical Engineering, Faculty of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565, Japan*

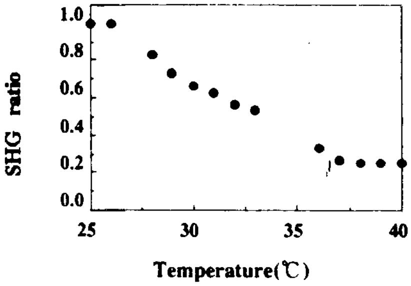
Potassium lithium niobate (KLN) is expected as a promising nonlinear material due to its superior optical and mechanical properties compared to potassium niobate (KN).[1] KLN has a tetragonal tungsten bronze crystal structure with a composition described by $K_3Li_{2-x}Nb_{5+x}O_{15+2x}$ for $0 < x < 0.5$. A variation in the mole fraction of lithium leads a wavelength for noncritical second harmonic generation (SHG) lying within the range of 790–920 nm at room temperature (RT).[1] However, difficulties in growing noncongruently melting KLN crystal of sufficient size and of reasonable uniformity of crystal composition still have remained.

In order to know the angular and temperature acceptances, the KLN seeded solution growth (TSSG) method. The starting charges were prepared by melt-charging of K_2CO_3, Li_2CO_3 and Nb_2O_5 with ratios of 33:23:44. Optimum RT phase matching was realized through maximization of the harmonic signal through fine turning of the wavelength of the Ti:sapphire laser which was used as the pump source. This crystal doubled 850 nm radiation for type I noncritical phase matching at RT. Figures 1 and 2 show the angular and temperature dependences of noncritical phase matched SHG from the KLN crystal grown by the TSSG method, respectively. The angular acceptance estimated from the graph is about 44 mrad·cm$^{1/2}$ which is larger than the theoretical value of 20 mrad·cm$^{1/2}$ evaluated from the reported value of refractive indices.[2] Although the reason for this difference remains unclear at present, it seems to be due to the inhomogeneity of the crystal. Compared with KN crystal, the KLN crystal exhibits larger temperature acceptance of 2.1°C·cm evaluated from Fig. 2. This result indicates that KLN would be more available for optical devices operating in various circumstances than KN.

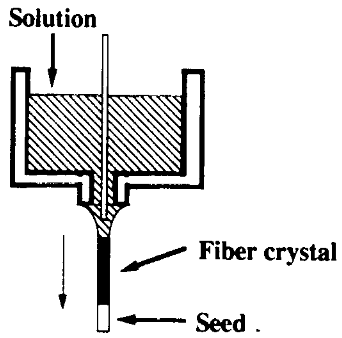
In spite of the superior properties of KLN, it is still difficult to grow KLN crystal with reasonable uniformity of crystal composition by TSSG method. Moreover, nonlinear optical fibers are of the great interest due to high confinement of incident light. Therefore, we have employed the novel growth technique (micro pulling down method μ-PD) by which a KLN can be formed as a small diameter fiber with much higher growth rate than TSSG method. This system would make possible to grow noncongruently melting crystal with uniform composition. Figure 3 shows the schematic diagram of the KLN fiber growth setup. The single crystalline KLN fibers were formed with a diameter of 50–800 μm ϕ and 20–100 mm in length. The a-axis for noncritical phase matching at RT corresponds with fiber growth direction. These



CThM6 Fig. 1. Angular dependence of noncritical phase matched second harmonic generation at room temperature from the bulk KLN crystal.



CThM6 Fig. 2. Temperature dependence of noncritical phase matched second harmonic generation from the bulk KLN crystal.



CThM6 Fig. 3. Schematic diagram of micro pulling down system used for the KLN fiber crystal growth.

fibers could double 790–850 nm radiations for type I noncritical phase matching at RT with cw Ti:sapphire laser, indicating the goal of transferring it later to diode laser. However the fiber with a tetragonal structure which shows optical nonlineality could be obtained in shorter wavelength (~800 nm), whereas it was difficult to grow fibers in the larger wavelength region (~850 nm or more).

In conclusion it has been demonstrated that KLN is a superior nonlinear material with larger temperature acceptance of 2.1°C·cm than KN. KLN fibers were grown by μ-PD method which showed the possibility to grow noncongruently melting KLN crystal with uniform composition. We observed blue light by frequency doubling of cw Ti:sapphire laser with these KLN fibers for noncritical phase matching at RT.

* *Electrotechnical Laboratory, Ministry of International Trade and Industry, 1-1-4, Umezono, Tsukuba, Ibaraki 305, Japan*
** *Institute for Material Research, Tohoku University, 2-1-1 Katahira, Aoba, Sendai, Miyagi 980, Japan*
† *Telecommunication Division, Mitsubishi Cable Industries, Ltd., 4-3 Ikejiri, Itami, Hyogo 664, Japan*

1. M. Ouwerkerk, Adv. Mater. **3**, 399 (1991).
2. J. J. Reid, M. Ouwerkerk, L. J. A. M. Beckers, Philips J. Res. **42**, 199 (1991).

CThN 4:30 pm

Convention Center Room B1

Technology for Ultrafast Systems

Stephen B. Alexander, *Massachusetts Institute of Technology, Presider*

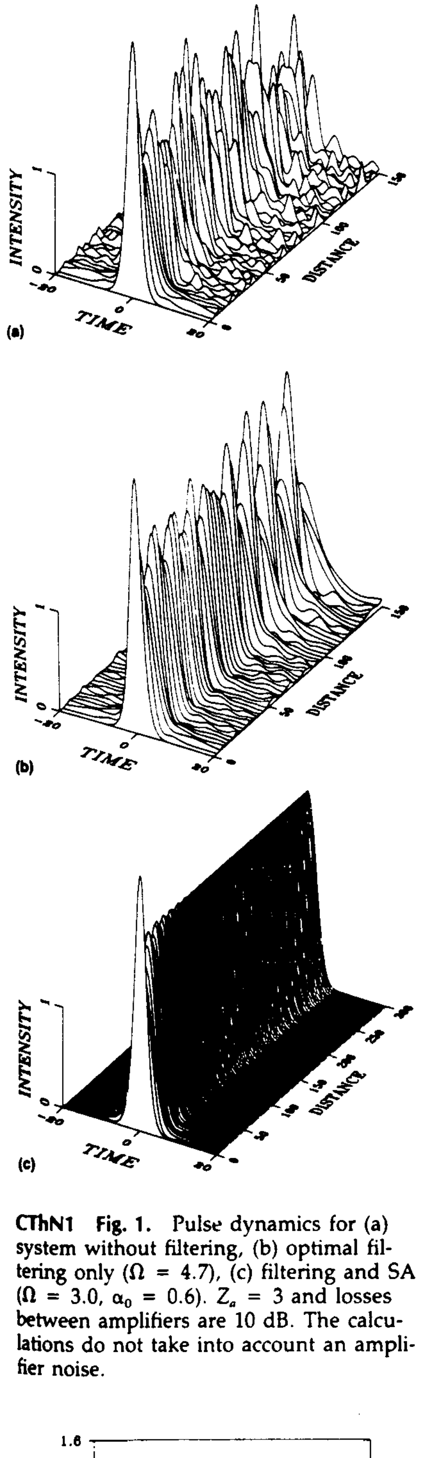
CThN1 797 4:30 pm

Unlimited soliton propagation and noise suppression in a system with spectral filtering and saturable absorption

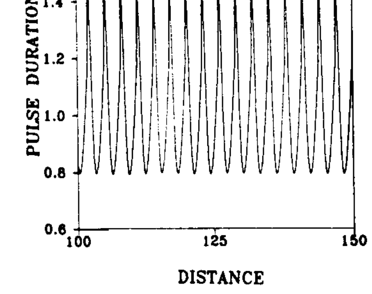
V. V. Afanasjev,* W. H. Loh, A. B. Grudinin, D. Atkinson,** D. N. Payne, *Optoelectronics Research Centre, Southampton University, Southampton S09 5NH, U.K.*

It is known that the use of relatively narrow filters in soliton communication systems reduces the perturbations to the soliton amplitude and frequency permitting an increase in the propagation distance. However, such an approach requires excess gain to compensate for soliton loss at the filters, so the system is intrinsically unstable due to the growth of non-soliton component and accumulation of ASE noise. Sliding filters[1] and nonlinear gain[2] were proposed to suppress this instability. But fabrication of sliding filters is technically complicated, and the steady-state pulse has a large chirp, so the transition to the steady state requires a large distance. The nonlinear gain may be used only in combination with excess linear gain, as otherwise the soliton tends to collapse even in the presence of filters. So in such a system, the non-soliton component growth is only decreased and the system still remains unstable. We propose the use of fast semiconductor saturable absorbers (SA) to achieve soliton stability over unlimited distances as well as a steady state pulse with low chirp.

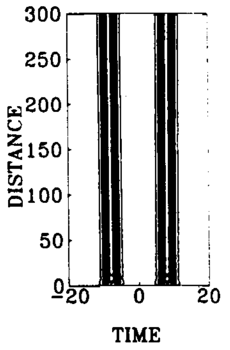
Let us consider SA with saturation intensity I_{sat} approximately equal to soliton peak intensity and saturation time significantly shorter than the pulse duration and a parabolic-shape filter with bandwidth Ω in soliton bandwidths. The absorption coefficient α depends on intensity $I(t)$ with $\alpha(I) = \alpha_0/(1 + I/I_{sat})$. If the additional loss for linear radiation due to the presence of the SA is higher than additional losses for the soliton due to the presence of both SA



CThN1 Fig. 1. Pulse dynamics for (a) system without filtering, (b) optimal filtering only ($\Omega = 4.7$), (c) filtering and SA ($\Omega = 3.0$, $\alpha_0 = 0.6$). $Z_a = 3$ and losses between amplifiers are 10 dB. The calculations do not take into account an amplifier noise.



CThN1 Fig. 2. Pulse duration at steady-state of Fig. 1(c).



CThN1 Fig. 3. Suppression of soliton interaction by SA and filtering ($\Omega = 3.0$, $\alpha_0 = 0.6$).

and filtering, then a small additional linear gain provides for stable soliton propagation, while the linear radiation is suppressed. There is a power threshold for the input pulse, below which the pulse is damped by the SA, while above threshold the stable soliton forms from the original pulse.

Computer results show that such a system allows significant improvement to the performance of solitons for communication. In particular, pulse durations may be greatly reduced such that the distance between amplifiers Z_a may be equal to 3 dispersion lengths for 10 dB losses between amplifiers. Figure 1 demonstrates the pulse dynamics for a system without filtering, with filtering only, and filtering plus SA. Without filtering the pulse is rapidly destroyed by the soliton resonance, while even optimal filtering only results in marginal improvement of the performance and the eventually growing pedestal destroys the soliton. The system with both SA and filtering gives indefinite steady-state propagation. Figure 2 shows that the steady state propagation is periodic with respect to Z_a with the pulse duration changes of $\pm 30\%$. Also, the SA and filter act on the pulse chirp in opposite directions, so the steady-state pulse has low chirp and the transition to steady-state is rapid. Steady state propagation has been achieved even for $Z_a = 5$ with 10 dB losses and $Z_a = 1$ with 20 dB losses, although the transition to steady state is slower. Figure 3 shows the suppression of soliton interaction by the combined action of both SA and filtering.

In our calculations we have assumed an instantaneous nonlinear response of the SA, while real SAs have response times of around 200 fs.[3] We show that the finite response time of the SA leads to an effect analogous to the soliton self-frequency shift, which can be suppressed by bandwidth-limited amplification.

In conclusion, we have found that the performance of soliton communication systems may be improved by incorporating of saturable absorption. Although the information transmission distance is limited due to the Gordon–Haus effect, the use of narrower filters with suppression of the non-soliton component allows the bit-rate to be increased, while the individual solitons remain ultimately stable.

*Russian Academy of Sciences, General Physics Institute 38 Vavilov Stree, 117942 Moscow, Russia
** Optoelectronics Research Centre, Department of Electronic and Electrical Engineering, University College London, Torrington Place, London, WC1E 7JE, U.K.

1. L. F. Mollenauer, E. Lichtman, M. J. Neubelt, G. T. Harvey, Electron. Lett. 29, 910 (1993).
2. M. Matsumoto, A. Hasegawa, Opt. Lett. 18, 897 (1993), and references therein.
3. M. Wegener, I. Bar-Joseph, G. Sucha, M. N. Islam, N. Saner, T. Y. Chang, D. S. Chelma, Phys. Rev. B 39, 12794 (1989).

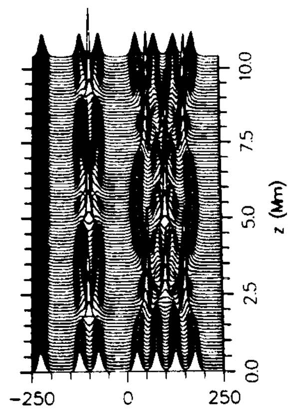
CThN2 **4:45 pm**

Phase conjugation for jitter and soliton–soliton compensation in soliton communications

N. J. Doran, W. Forysiak, *Department of Electronic Engineering and Applied Physics, Aston University, Aston Triangle, Birmingham B4 7ET, U.K.*

It has recently been pointed out that mid-point optical phase conjugation (OPC) can compensate for self-phase modulation in addition to linear dispersion in periodically amplified systems.[1] Here we apply the concept to soliton communication system. The principle is that conjugation is equivalent to "time" reversal in Nonlinear Schrödinger Equation Systems. In periodically amplified systems soliton concepts apply within the average soliton limit.[2,3] Thus a mid-point conjugation will lead to a complete reversal of soliton effects provided the average soliton limit is obeyed. Figure 1 shows in particular the reversal of soliton-soliton interactions via this method for a 10,400-km system operating at 20 Gbit/s. The output is almost identical to the input with no effects from soliton-soliton interaction.

OPC has, however, a further potentially more significant beneficial effect in soliton systems, namely the reduction of Gordon-Haus jitter. The use of post-propagation dispersion compensation has recently been shown to reduce the Gordon-Haus RMS timing jitter by a factor of 2.[4] OPC provides



CThN2 Fig. 1. Mid-point phase conjugation reversing soliton-soliton interaction in a 10,400 km amplified system.