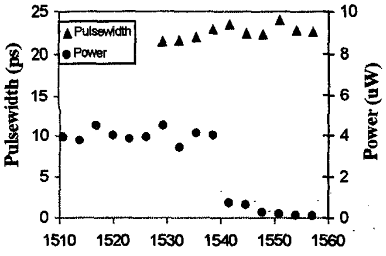

**CThA6 Fig. 5.** Variation of the pulsewidth and output power vs wavelength.

variation between them on pulsewidth and power.

In summary, we have demonstrated a simple, totally fiber-pigtailed, actively mode-locked laser source, generating 10 simultaneously synchronised wavelength channels, each at 10 GHz and producing as short as 21 ps pulses. The laser performance may be extended to higher rates and more channels with the simple substitution of the modulator and the Fabry-Perot filter elements.

The primary advantage of the source is its capability to generate temporally synchronised pulse train and may be used as a clock source may in WDM/TDM systems or systems requiring synchronised multi wavelength sources as for example for high speed optical logic.

1. N. Park, J. Dawson, and K. Vahala, IEEE Phot. Tech. Lett. **4**(6), 540–541 (1992).
2. K. Poguntke, J. Soole, A. Scherer, H. LeBlanc, C. Caneau, R. Bhat, M. Koza, Appl. Phys. Lett. **62**(17), 2024–2026 (1993).
3. S. Lewis, M. Guy, J.R. Taylor, R. Kashyap, Electr. Lett. **34**, 1247–1249 (1998).
4. T. Morioka, H. Takara, S. Kawanishi, O. Kamatani, K. Takigushi, K. Uchiyama, H. Takahashi, M. Yamada, H. Ono, Electr. Lett. **32**, 906–907 (1998).
5. H. Shi, G. Alphonse, J. Connolly, P. Delfyett, Electr. Lett. **34**(2), 179–181 (1998).

### CThA7 9:45 am

### 10-GHz repetition-rate pulse trains by asynchronous frequency-modulation of an Er-Yb laser

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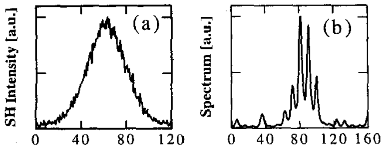
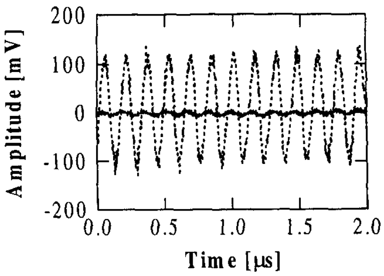
Generation of symmetric, chirp-free picosecond pulses at high-repetition-rate and with short- and long-term stability is a key feature for soliton-based optical transmission systems. Spectral filtering of an intracavity frequency-modulated (FM) laser has been recently demonstrated to be a valid alternative technique to conventional FM mode-locking for generation of transform-limited pulse trains with high stability against cavity length fluctuations.[1,2] This operating regime is based on a sinusoidal phase modulation of the laser field at a frequency slightly detuned from the free spectral range of the laser cavity. The asynchronous modulation results in a broad FM spectrum composed by a large number of modes with a precise linear phase locking condition,[3] which enables the generation of transform-limited pulses after suitable spectral filtering.[4]



**CThA7 Fig. 1.** (a) Typical noncollinear autocorrelation trace of a single pulse of the 9.4-GHz pulse train, and (b) corresponding spectrum obtained after spectral filtering of the FM laser field. Pulse duration is ~23 ps; effective modulation index is ~5π.

In this work we experimentally demonstrate the generation of nearly transform-limited picosecond pulse trains at 1.5 μm using a diode-pumped bulk Er-Yb:glass laser FM-operated by an intracavity LiNbO$_3$ resonant phase modulator at 9.4 GHz, near the extreme repetition rate achievable with a bulk solid-state laser. The FM optical field from the laser is sent to a custom-made fiber Bragg grating acting as a sharp cut-off filter in reflection, and the filtered signal is derived through a three-port optical circulator. In Fig. 1 we show a typical autocorrelation trace of the pulse, together with the corresponding filtered FM spectrum.

To assess the suitability of the pulse trains for soliton transmissions, a detailed experimental analysis of the short- and long-term stability has been performed, and the results are compared with those obtained by conventional FM mode-locking. Two instability mechanisms, namely relaxation oscillations and supermode competition, are typically present in both operating regimes and are not appreciably influenced by the cavity detuning from modulation frequency. Intensity noise at the relaxation oscillation frequency of ~30 kHz has been suppressed, with residual fluctuations of less than 0.1%, by an optoelectronic feedback loop acting on the pump diode current. Supermode competition can be avoided by either operating the laser in the fundamental-harmonic with a very short cavity length or by a passive intracavity etalon filter which enables one supermode only to oscillate. A further amplitude instability with a typical frequency equal to the frequency detuning, is observed when the modulator is asynchronously driven. This kind of modulation has been attributed to a beating between two competing Bessel modes of the FM-operated laser and is enhanced by external perturbations (see Fig. 2, dashed line). This behavior is likely to be ascribable to longitudinal mode-hopping observed with the laser running cw, and may be reduced to less than 2% (see Fig. 2, solid line) or possibly eliminated by reducing the spatial hole burning in the active material; work is in progress in this direction. Differently from resonant FM mode-locking, asynchronous modulation is, however, extremely robust against frequency detuning and does not require any particular cavity length stabilization; the stability against frequency detuning increases in fact from about 5 kHz of FM mode-locking to more than 300 kHz when the laser is FM-operated.



**CThA7 Fig. 2.** Amplitude modulation instability of the pulse train at the detuning frequency induced by mode-hopping of FM modes (dashed line), and residual amplitude oscillation after suppression of FM mode competition (continuous line). The cw time-averaged value of the signal is 900 mV.

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1. S. Longhi, S. Taccheo, and P. Laporta, Opt. Lett. **22**, 1642 (1997).
2. S. Longhi, G. Sorbello, S. Taccheo, and P. Laporta, Opt. Lett. **23**, 1547 (1998).
3. S. Longhi and P. Laporta, Appl. Phys. Lett. **73**, 720 (1998).
4. P.V. Mamishev, Opt. Lett. **19**, 2074 (1994).

## CThB 8:00 am–10:00 am
Rooms 316/317

## Quasi-Phase-Matching

Mark Alan Arbore, *Lightware Electronics Corp., USA, Presider*

### CThB1 (Tutorial) 8:00 am

### Quasi-phasematching: materials, devices, and applications

M.M. Fejer, *E.L. Ginzton Laboratory, Stanford University, Stanford, California 94305 USA; E-mail: fejer@leland.stanford.edu*

Quasi-phasematching (QPM) has evolved into a widely used technique in nonlinear optics. This tutorial covers the fundamentals of QPM, the status of microstructured materials, use in conventional frequency conversion applications, and novel applications in areas such as spatial and temporal pulse shaping and optical signal processing.