erated THz-wave above 7 THz is due to the strong absorption in DAST. To generate frequencies higher than 7 THz, we are investigating optimum conditions such as crystal thickness, input wavelengths and the focusing diameter of the input beam.

In conclusion, we have demonstrated widely tunable THz-wave generation with thin DAST crystals. The frequency of the THz-wave was continuously tuned in the range of 1.5 to 6.5 THz by varying the KTP crystal angle in the OPO cavity. It is found that DAST crystal is attractive material for THz-wave generation with wide tunability ranging from 0.2 to 6.5 THz by selecting crystal thickness.

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CTuC6 **9:15 am**

Quasi-phase Matched Tunable Mid-infrared (8–12 μm) Difference Frequency Generation by Total Internal Reflection in Isotropic Semiconductors

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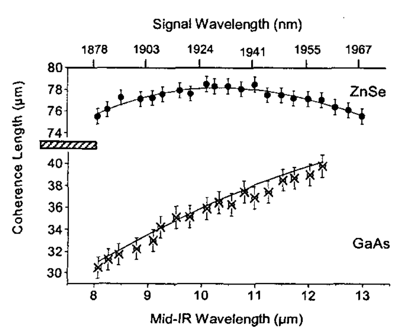
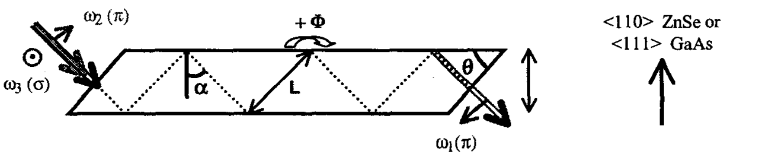
Environmental monitoring and defence applications call for efficient mid-infrared tunable sources. To reach such a goal, one can take advantage of optical parametric oscillators (OPO) pumped by near infrared commercial laser sources. Semiconductors of the main technological stream (GaAs, InP and ZnSe) are good candidates due to high transparency in the 1–15 μm range, good mechanical properties, high optical damage threshold and particularly high $\chi^{(2)}$ values. Integration with the pumping source may also be envisaged. However, these materials are isotropic, so that birefringence phase matching is impossible.



CTuC6 Fig. 1. Coherence length dispersion for mid-IR DFG (line: theory; scatter: experiment).



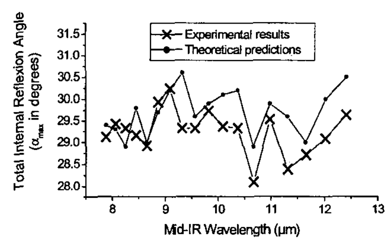
CTuC6 Fig. 2. QPM-TIR scheme. $\Phi = \phi_3 - \phi_2 - \phi_1$, ϕ_m is the Fresnel phase shift at reflection for wave *m*. L is about an odd number times Λ_C.

In this communication, we present what we believe to be the first largely tunable (8–12 μm) difference frequency generation DFG obtained in GaAs and ZnSe plates, using quasi-phase matching by total internal reflection QPM-TIR in one single slab, as proposed by Bloembergen 30 years ago.[1] This technique has already been used by Boyd[2] and Komine[3] for second harmonic generation, and is extended in this paper to a three-wave interaction ($\omega_3 > \omega_2 > \omega_1$).

In our experiment, pump beams for DFG are the signal and idler (frequencies ω_3 and ω_2, respectively) outputs of a YAG:Nd^{3+} pumped $LiNbO_3$-OPO delivering a few mJ on the twin beams, in the spectral range from 1.8 to 2.5 μm, with about 60 GHz linewidth. Outputs are processed in order to obtain 500 μm diameter superimposed parallel beams. Coherence lengths Λ_C and their dispersion are determined by a wedge method in GaAs and ZnSe prisms[4] (apex angles : 2° for GaAs and 3.1° for ZnSe). The ZnSe crystals have been grown by solid state recrystallization of high purity polycrystalline plates.[5] The GaAs wafers are from Atomergic Chemetals Corp. The mid-IR wave is measured via a nitrogen cooled HgCdTe detector through adequate filtering. As shown in figure 1, agreement is excellent between experimental results and theoretical estimations of Λ_C as a function of the mid-IR wavelength (Sellmeier formulas are from Adashi[6] and Li[7]).

QPM-TIR is realized in ⟨110⟩ ZnSe and ⟨111⟩ GaAs wafers (figure 2). The wafer thicknesses t are 885 μm and 315 μm, the beveled angles θ are 27° and 20.5°, respectively. These values have been calculated through a model which will be described, and using our coherence lenghts measurements. The two pump beams have different polarizations which allows Fresnel birefringent reflection at the interfaces.

We determined the total internal reflection angle α_{max} corresponding to the maximum DFG efficiency. Maximization is obtained through rotation of the wafers relatively to the pump beam propagation. We plot α_{max} vs. the mid-IR wavelength as shown in figure 3. The curves display a good agreement between the experimental results and the theoretical predictions which take into account both the polarizations of the interacting waves, and the index dispersion.



CTuC6 Fig. 3. Total internal reflection angles for QPM-TIR.

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CTuC7 **9:30 am**

Fiber Laser Pumped Continuous-wave Singly-resonant Optical Parametric Oscillator

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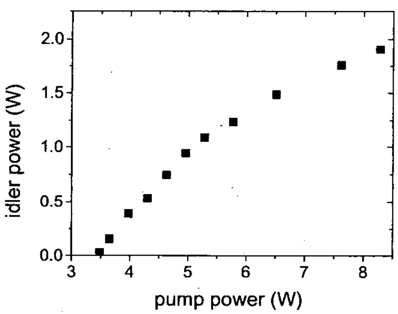
Continuous-wave (CW) optical parametric oscillators (OPOs) are efficient and widely tunable light sources in the mid-infrared wavelength range. In this contribution we report on the first fiber-pumped CW OPO. The OPO is singly resonant (SRO) and generates idler wavelengths in the range of 3.0 μm to 3.7 μm with a maximum output power of 1.9 Watt.

The OPO pump laser is based on a 20-m long ytterbium doped double-clad Large Mode Area (LMA) fiber, where the D-shaped inner cladding serves as a pump core. The fiber is pumped by a diode laser at a wavelength of 980 nm, which emits a power of up to 30 W. The laser resonator is set up as a unidirectional ring cavity with an enclosed double grating for spectral narrowing and wavelength tuning. With this setup, the fiber laser wavelength can be tuned from 1031 to 1100 nm,

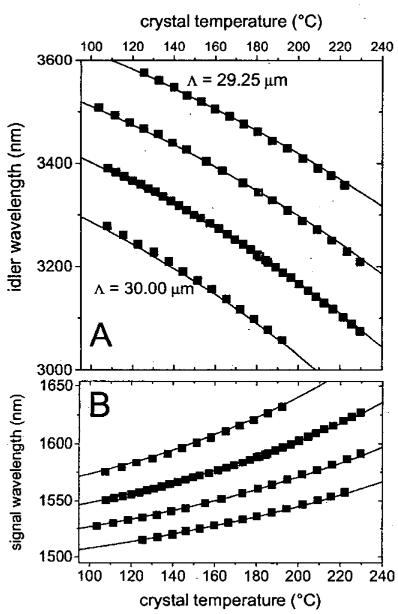
and an output power of up to 9 W can be achieved. Without further precautions, the spectral bandwidth is less than 3 GHz.

The SRO is based on a 40 mm long periodically poled lithium niobate (PPLN), which carries four channels with grating periods of Λ = 29.25, 29.50, 29.75, and 30.00 μm. The crystal is placed in a four-mirror bow-tie ring cavity, which is resonant only for the signal wave.

Fig. 1 shows the generated idler power at a wavelength of 3.20 μm as a function of the fiber laser power. The pump power at threshold is 3.5 W. At the maximum pump power of 8.3 W, the SRO generates 1.9 W. This corresponds to a crystal-internal quantum efficiency of 80%. The residual power transmission of the signal wave at one of the cavity mirrors is 90 mW. The output power level remains highly stable with fluctuation of less than 1% RMS over one hour.



CTuC7 **Fig. 1.** Idler wave output power at a wavelength of 3.20 μm from the CW SRO as a function of the pump power provided by the fiber laser at a wavelength of 1064 nm. The grating period is 29.75 μm, the crystal temperature 187.7°C. The pump power at threshold is 3.5 W, and the maximum idler power is 1.9 W.



CTuC7 **Fig. 2.** The SRO output wavelengths as a function of crystal temperature at a fixed fiber laser wavelength of 1064 nm for four grating periods: Λ = 29.25, 29.50, 29.75 and 30.0 μm. Part A: idler wavelength, part B: signal wavelength. The measured values (dots) agree well with the theoretical curves (solid lines) calculated from the Sellmeier equations.[1]

For each of the four grating periods, the SRO output wavelength is tuned by changing the temperature of the PPLN crystal (Fig. 2). It can be seen, that the signal and idler wavelengths cover the ranges from 1515 to 1632 nm, and from 3057 to 3575 nm, respectively, in good agreement with theory.[1]

The main advantage of using a tunable pump source is that the SRO output can be tuned simply by tuning the pump wavelength.[2] In our experiment, both, the PPLN grating period and the crystal temperature are kept constant (29.5 μm and 144.9°C, respectively). By tuning the pump wavelength from 1032 to 1095 nm, the signal wavelength varies between 1543 and 1575 nm, and the idler wavelength tunes from 2995 to 3693 nm (Fig. 3). The grating control of the fiber laser wavelength enables a scan over the entire idler wavelength range within less than a second. The resolution limited bandwidth as implied from the signal bandwidth (<0.8 cm^{-1}, resolution limited) and pump bandwidth (0.1 cm^{-1}) is 0.9 cm^{-1}.

In conclusion, the Yb fiber laser pumped CW SRO is a highly efficient source of tunable, high-power, mid-infrared radiation. The easy wavelength tunability of the fiber laser leads to an easy coverage of a considerable portion of the so-called "fingerprint" spectral region of organic molecules, which is important for a sensitive and selective detection of molecular trace gases.

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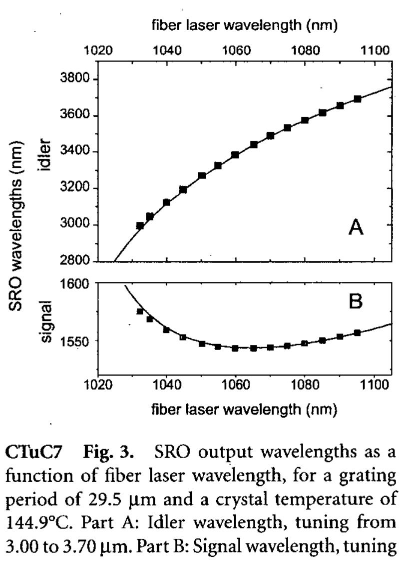

CTuC7 **Fig. 3.** SRO output wavelengths as a function of fiber laser wavelength, for a grating period of 29.5 μm and a crystal temperature of 144.9°C. Part A: Idler wavelength, tuning from 3.00 to 3.70 μm. Part B: Signal wavelength, tuning from 1543 to 1575 nm. The measured wavelengths (dots) are in good agreement with the theoretical tuning curves (solid lines), calculated from the Sellmeier equations.[1]

CTuD **8:00 am–9:45 am**

Room: 104B

Pulsed Solid State Lasers

Iain T. McKinnie, Coherent Technologies, Inc., USA, Presider

CTuD1 **8:00 am**

High Power, Passively Modelocked Quasi-cw Nd:YLF Laser with Feedback for Q-switch and Spike Suppression

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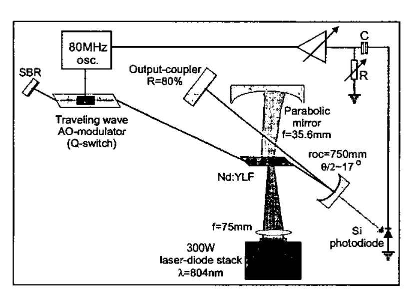
Erwin Bente, Eindhoven University of Technology, Inter-University Research Institute COBRA on Communication Technology, Department of Electrical Engineering, Opto-Electronic Devices Group P.O. Box 513, 5600MB Eindhoven, The Netherlands.

We present a promising approach to scaling the power of modelocked lasers by operating them quasi-cw. This could match the pulse repetition rate requirements of many applications. Active stabilisation is then deployed to minimise the time taken to reach a steady cw state.

Recently, Schibli et al.[1] have reported an active feedback loop to control the Q-switching dynamics of passively modelocked lasers involving modulating the laser diode drive current in response to changes in the output power of the laser. Here we report a technique aimed at suppressing the much stronger spiking which follows laser turn on. This also serves to suppress Q-switch modelocking hence extending the useful parameter range of a Saturable Bragg-reflector (SBR) for stable cw modelocking.

An intracavity acousto-optic Q-switch was used to modulate the laser loss in response to laser spiking. This is similar to prelase spike suppression reported by Bollig et al.,[2] but its application to a modelocked laser is novel.

A schematic of the laser oscillator is shown in figure 1. The pump source was a stack of 8 fast-axis collimated 40 W cw diode bars at 804 nm,[3] operated quasi-cw (200 μs pulse at 100 Hz) at a peak power of 300 W. The total pump absorption



CTuD1 **Fig. 1.** Schematic of the laser cavity showing the feedback loop.