A pump enhanced ns – OPO for THz generation

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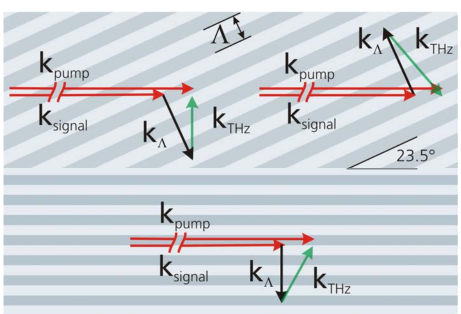
***Abstract*—A nanosecond OPO pumped by a single mode Q-switched Nd:YVO_4 laser for terahertz generation in slant stripe periodically poled lithium niobate is presented. The oscillation threshold is overcome by stabilized pump enhancement and lowered by means of injection seeding by a grating stabilized, tunable diode laser.**

I. Introduction And Background

THE generation of Terahertz (THz) radiation with nanosecond OPOs or OPGs has been realized by several groups[1] using bulk lithium niobate as nonlinear material. Here we report on experiments using periodically poled lithium niobate (PPLN) in order to realize a powerful nanosecond OPO with output in the THz frequency range. Furthermore, the lithium niobate crystal is not poled in a conventional way but poled with tilted periods[2] (so called slant stripe periodic poling) and even periods with a k-vector perpendicular to the pump.

The scheme of the slant stripe poling has the advantage of achieving a perpendicular emission of THz radiation and a parallel propagation of the pump and signal wave without the need of tight focusing as shown on the left side of the k-vector diagrams. As a consequence, the path of THz radiation inside the crystal is minimized to avoid the high absorption in



lithium niobate. By having no walk off between the pump and signal wave, these two can interact over the whole crystal length making long crystals feasible. In the case of poling at 0 degrees (see bottom scheme of the picture) the advantage of parallel and good interacting pump and signal wave is the same, but the THz radiation is emitted under an angle which corresponds to the Cherenkov angle.

The realization of a resonator for the signal wave (which is for example 1068 nm when pumped at 1064 nm and radiating at approx. 1 THz) is challenging because of the need to transmit the pump radiation through the resonator mirrors. Our approach is to build a pump enhanced OPO cavity, which is stabilized to the 1064 nm pump laser.

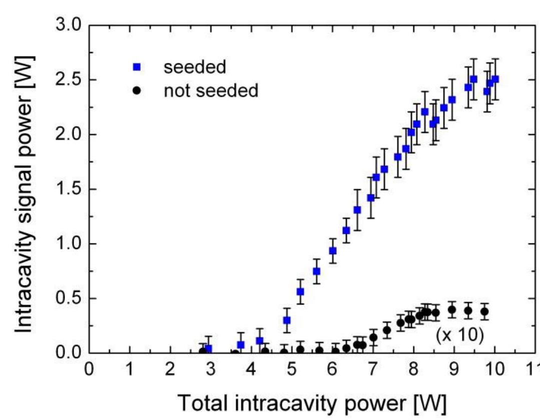
For the purpose of spectral narrowing and lowering the threshold the OPO is also injection seeded using a grating stabilized cw diode laser.

II. Results and Discussion

The slant stripe periodic poling of the crystal leads to momentum conservation as depicted in the k-vector diagrams above. There are two possibilities for the phase matching, which lead to different THz frequencies radiated at different angles. To avoid the internal total reflection, the preferred option is the one with perpendicular emission of THz with respect to the crystal surface. However, the option shown on the right side of the figure has a longer interaction length between the THz and the infrared (pump and signal) beams. So the oscillation at this specific THz frequency is expected to have a lower threshold, even though without appropriate crystal cuts or other outcoupling techniques it is not useable outside the crystal.

In our first experiments the OPO was operated in a configuration which is related to emission of THz at an angle of about 45 degrees (see top right k-vector diagram in the picture above). This was done by seeding the corresponding signal wave. The OPO was pumped by a single mode Q-switched Nd:YVO_4 laser, emitting 18 ns pulses up to 0.5 mJ at a 10 kHz repetition rate. For the purpose of pump enhancement the OPO cavity was stabilized by a Hänsch-Couillaud circuit.

The resonator internal power of the corresponding infrared signal wave is shown below for seeded and not seeded setup.



The achieved power of the signal wave was in the Watt range which corresponds to generation of powerful THz radiation. In the time diagram the depletion of the pump can be clearly seen. The pump pulse duration without OPO operation is enlarged because of the use of the enhancement cavity. In this diagram, the pulse energies should not be

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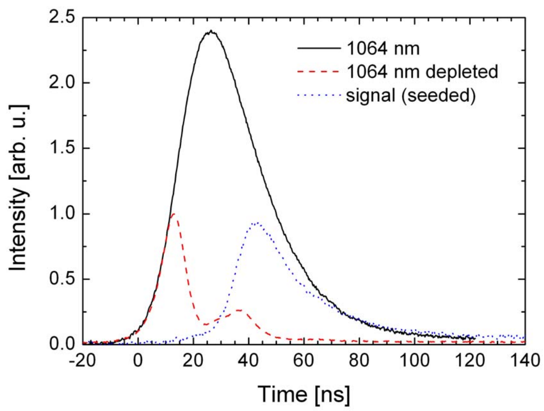
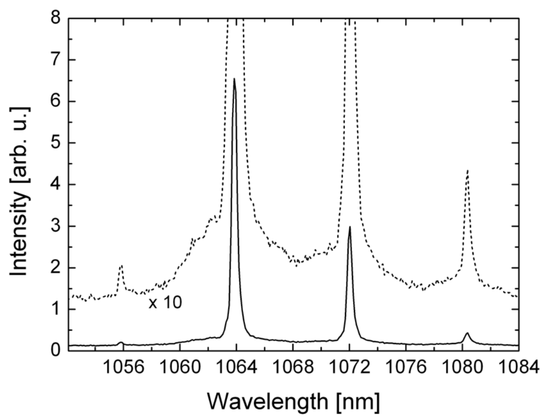
compared, because the traces show intracavity (pump enhanced) pulses, which cannot be compared as easy as time traces of conventional OPG-experiments, for example. Here they should just show the qualitative behavior of the waves.

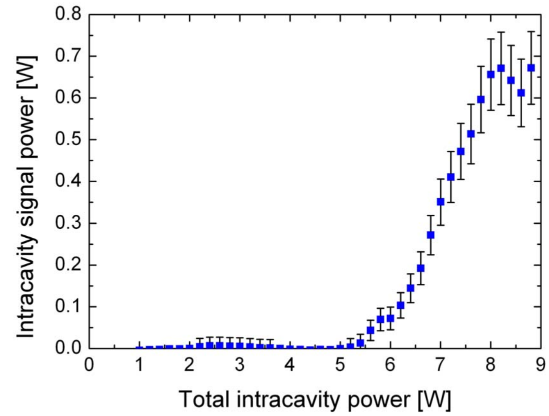


Another proof of the powerful operation of the OPO is the fact that not only the seeded and amplified signal wave at about 1072 nm is generated but also a wavelength at 1080 nm which corresponds to the difference frequency between the signal and the generated THz radiation. Furthermore, the sum frequency between the pump and the THz frequency at about 1056 nm is also observed, indicating the high efficiency of this source.

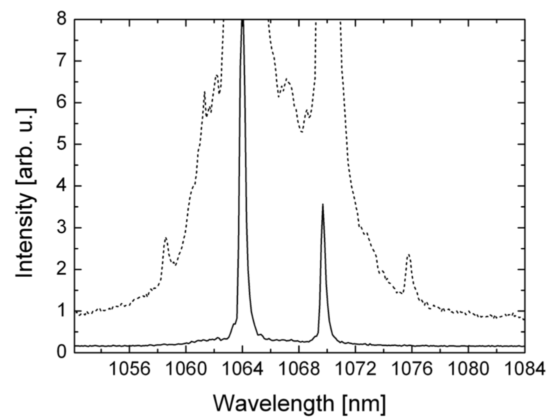


Recently we also succeeded in the operation of the OPO at the grating with a k-vector perpendicular to the pump (see lower k-vector diagram above). Here the pump enhancement turned out to be more critical because the domain walls of the crystal poling disturb the OPO cavity mode. The power dependency can be seen below.

Although the achieved signal power is not as high as in the slant stripe experiment, this result is very promising because the output coupling techniques for the THz radiation have been already proven by several groups[3]. In our case it could not yet be implemented, because this grating is in between two other slant stripe gratings of 3 mm width. So our crystal will be cut and silicon prism couplers will then be used for output coupling.



Another proof of the powerful operation of this grating can be seen again in the spectrum of the OPO below.



The signal wave at about 1070 nm exactly matches our calculations and will lead to emission of THz radiation at 1.5 THz. Even if the cascaded process to about 1076 nm and the sum frequency generation of 1058 nm are not as strong as in the slant stripe setup, they show the efficiency of this source once more.

In the near future our crystals will be exchanged, so that the THz radiation generated in the 0 degrees grating can be coupled out with silicon prisms.

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