Development of a Mid-Infrared Laser for Study of Infrared Countermeasures Techniques

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ABSTRACT

Countermeasures against heat seeking missiles require access to efficient laser sources, which should emit wavelengths at band I, II and IV. Efficient diode pumped solid-state lasers, combined with efficient non-linear wavelength shifters, allow the development of practical tuneable mid-IR countermeasure sources. The paper describes the requirements and the development of a tabletop laser source for study of DIRCM techniques. Jamming laser systems must be able of creating pulse sequences in the frequency range between 100 Hz and 10,000 Hz, including the capability to mix and sweep the jam frequency. A Nd:YVO_4 pump laser with maximum pump power of 3 Watt and pulse length of 10 ns, and a maximum modulation frequency of 100 kHz was selected. A linear single resonant OPO cavity with 30 mm long, 1mm thick PPLN crystals was build. With the tabletop laser system we were able to generate wavelengths from 1.5 to 4 micron. In band I, at 2 micron we can generate between 400-550 mW, and in band II, from 3-4 micron we can generate 130-160 mW laser jam power. The beam quality (M^2) is approximately 2.5. The power efficiency for the idler was 8.8%, while the slope power efficiency was 15%. Jam patterns are generated by use of an acousto-optic modulator.

Keywords: OPO, Nd:YVO4, PPLN, Laser, MID-IR, Countermeasures

1. INTRODUCTION

The first project to study laser-jamming technology started at TNO-FEL in 1995, after initial assessment of the vulnerability of passive sensors. A solid-state laser source radiating at 4 µm has been developed in that project. A follow-up project was defined in which the laser source was used to study damage of IR sensors at close range using strongly focused laser beams. The confidence gained from these laboratory experiments has initiated the current project. In this project a new laser source for jamming experiments has been developed in a laboratory set-up. Under certain provisions, this set-up can be used in field experiments. With the availability of a laser jamming source there is the capability to generate jamming patterns to study and test the jamming of infrared guided missiles. For dazzling and damaging more powerful lasers have to be developed.

In Section 2 of this paper the laser requirements are derived from available DIRCM system requirements. Based on the requirements, the components for the laser are selected. Section 3 describes the construction and characterisation of the assembled DIRCM laser. The laser is built using solid state laser technology using non-linear frequency conversion in an optical parametric oscillator. With the development of a laser jamming system the capability to generate and investigate jam patterns against various seekers will become available for the Royal Netherlands Air Force.

Heat-seeking missiles like the Stinger, Sidewinder, and others are an ever-increasing threat for fixed-wing and rotary-wing aircraft. The traditional countermeasures like maneuvering and flares have a reduced effectiveness against modern missiles. The experience of Desert Storm has shown that from all US aircraft most losses fell to IR SAM missiles.

In the Kosovo crises air campaigns were conducted at high altitude to reduce this risk, but this has also reduced the effectiveness of air strikes. In addition to the development of advanced decoy flares and infrared jammers also a new method is being developed to counter heat-seeking missiles. It is based on active sources that deceive, dazzle or (sensor) damage these missiles.

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Practical use of such countermeasures, therefore, requires access to efficient laser sources, which should preferably be tuneable to any wavelength within the 3-5 μm spectral band. In the past there has been a lack of such sources. However, the advent of efficient diode pumped solid-state lasers, combined with efficient non-linear wavelength shifters, has recently paved the way for development of practical tuneable mid-IR countermeasure sources, and the first of such systems are about to be installed on airborne platforms for protection against IR homing missiles.

2. LASER SPECIFICATION DERIVED FROM DIRCM REQUIREMENTS

Optical parametric oscillators (OPOs) are the laser sources of choice when needing broad continuous tunablility, high peak power (>1 kW), and high (>30%) conversion efficiency. It is generally adopted that a jammer to signal (*J/S*) ratio of >30 dB is required. For the 3-5 μm band reference values for the aircraft signatures are in the range 10-1000 W/sr [1,2] depending on aspect angle.

The directed energy of the laser reduces the required jammer energy in comparison to a lamp based jammer system. The required laser power is therefore a function of the laser divergence. In most Directed Infrared Countermeasure (DIRCM) system designs, an infrared Focal Plane Array (FPA) camera is used to passively track the threat. These cameras typically have a field of view (FOV) of 4 x 4° and 256 x 256 pixels, which yields an instantaneous field of view (IFOV) resolution of 0.3 mrad. The divergence of the laser beam must be in balance with this spatial resolution of the tracking camera. The laser beam divergence also needs to be compatible with the update rate of the camera (typically 400 Hz) to reach the required time on target even when the missile or the platform is manoeuvring.

Furthermore, we must keep in mind the fact that the camera will track the plume of the threat missile, whereas the jamming beam must be pointed at the missile seeker head. Given a typical missile length of 2 m, seen at an aspect angle of 30°, the separation of aim point and tracking point, projected perpendicular to the line of sight, can be as large as 1 m. At 1000 m this is equivalent to 1 mrad. Based on the above a laser beam divergence between 1 and 2 mrad seems adequate.

For a 1 mrad laser beam divergence, the required laser power is 1 W. This is based on a solid angle of 10^{-6} sr (1 mrad beam divergence) an aircraft signature of 1000 W/sr and a *J/S* ratio of 1000.

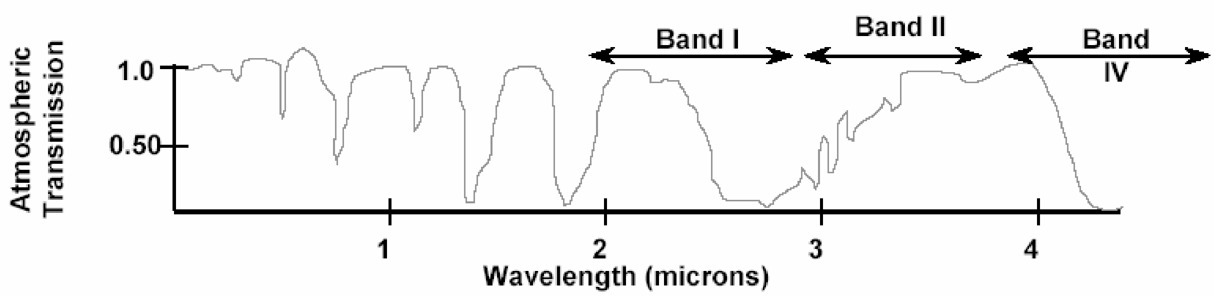

Figure 1 *Wavelengths bands commonly used by seekers*

The laser has to operate in three wavelength bands, which are depicted in Fig. 1. These bands are selected since most of the IR guide missiles make use of one of these bands. The missiles use these bands since air targets are very hot and emit a lot of thermal radiation in these bands. Furthermore, the atmospheric transmission is relatively good.
In addition, detectors in these wavelength bands are available. For the 1-3 μm band uncooled PbS detector cells are used, whereas for the 3-5 μm band cooled PbSe or InSb detectors are used. The more advanced seekers use the 3-5 μm band.

In adverse weather the jamming laser will experience stronger attenuation in the atmosphere. This affects the maximum range at which it can deceive an incoming IR guided missile. At the same time, the missiles also have more difficulty in acquiring their targets, since they experience a stronger atmospheric extinction of their target signal as well. Thus in effect, the laser jamming system is not sensitive to weather/environmental conditions as far as attenuation is concerned, since the jamming laser and the IR guided missile experience the same attenuation losses.

Wavelengths above 4 µm are more difficult to generate since single, PPLN based, OPO systems have severe absorption losses above 4 µm. Therefore, a more complex tandem OPO system has to be used or a single OPO system with a less powerful laser pump source.

It can be shown that an effective jamming source needs to generate modulated infrared light. The jamming modulation frequency/pattern has to be similar to the modulation patterns that the reticle/conscan/rosette-scan seeker generates out of the target radiation.

We know from various sources that jamming laser systems must be able to create pulse sequences in the frequency range typically between 100 Hz and 10,000 Hz, including the capability to mix and sweep the jam frequency. These high frequencies dictate that diode pumped laser pump sources have to be used, since flash lamp pumped laser pumps do not operate well above approx. a few hundred Hertz.

As OPO lasers make use of a non-linear optical crystal, high peak powers are required. Therefore, pulsed pump lasers are used. The laser light is stored in an optical cavity and released in a very short intense burst of light. Also, the mid-infrared light generated in the OPO light is therefore pulsed. The laser pulse length can vary, but is typical in the 1-100 ns regime. The pulse length needed for the jam patterns is normally much longer than these laser pulse lengths. Therefore, a jamming pulse has to be created by filling a jam pulse with a number of laser pulses as shown in Fig. 2. The time delay introduced in the seeker electronics smears out the individual laser pulses to the required jam pulse.

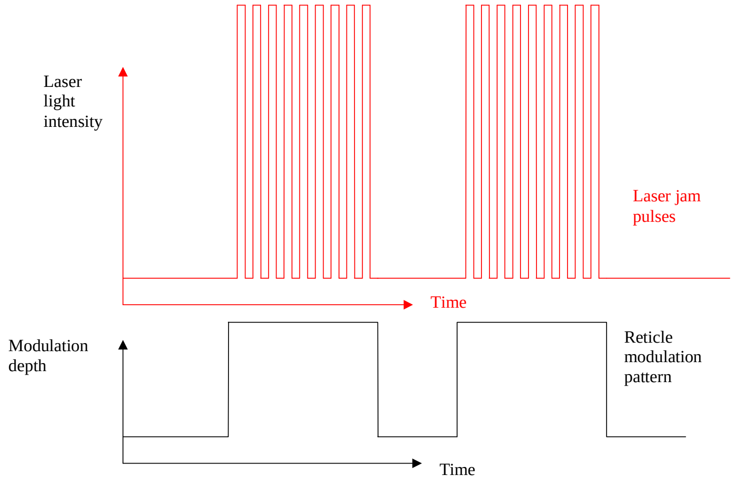

Figure 2 Laser jam source intensity versus time and reticle modulation pattern

In summary the operational laser requirements are provided in the following table:

Table 1: General operational DIRCM laser requirements.

Wavelength	2-5 µm
Modulation frequency	20-50 kHz

In case of passive tracking a laser beam divergence between 1 and 2 mrad is most realistic [2]. The required laser power in this case is summarised in the Table 2.

Table 2: Required laser power for an aircraft signature of 10 or 1000 W/sr a J/S ratio of 30 dB and a beam divergence of 1 and 2 mrad.

	10 W/sr	1000 W/sr
1 mrad	10 mW	1000 mW
2 mrad	40 mW	4000 mW

The required beam quality depends on the optical aperture that is used. If we assume that we can have an aperture that allows a beam diameter of 15 or 25 mm, we can calculate the minimum required beam quality to arrive at a beam divergence of 1 or 2 mrad, see Table 3.

Table 3: Maximum allowed beam quality (M^2) for a laser beam at λ=5μm, and for a required laser beam divergence of 1 or 2 mrad with an initial optical beam width of 15 or 25 mm.

M^2	1 mrad	2 mrad
15 mm	<2.3	<4.7
25 mm	<3.9	<7.9

It is not our objective to build a jam laser that will be incorporated in a flyable operational DIRCM system. The laser will be used to study infrared countermeasure techniques in laboratory experiments and during field trials. Therefore it does not have to be as powerful as indicated in the above tables, which were derived for an operational system.

3. CONSTRUCTION AND CHARACTERISATION OF LASER SOURCE

The acquired pump laser is a Coherent Vector, model 1064-3000-30. This is a diode pumped Nd:YVO_4 laser with a specified maximum average output of 3 Watt. At 30 kHz the pulse energy is approx. 100 µJ. At higher pulse rates the pulse energy decreases, whereas at lower pulse rates the average power decreases but pulse energy increases (see Table 4).

Table 4: Measured characteristics of Coherent Vector pump laser.

Rep rate (kHz)	Pulse energy (µJ)	Average power (W)	Peak power (kW)	Pulse length (ns)
5	288	1.44	57.6	5.0
10	160	1.60	30.2	5.3
15	132	1.98	17.6	7.5
20	118	2.35	14.4	8.2
30	103	3.1	11.2	9.2
40	78	3.1	6.78	11.5
50	62	3.1	4.43	14
60	52	3.1	3.25	16
70	44	3.1	2.59	17
80	39	3.1	2.05	19
90	34	3.1	1.70	20
100	31	3.1	1.35	23

A multi-grating PPLN crystal manufactured by Deltronic is used. The crystals have a thickness of 1 mm and a length up to 50 mm. For the laser 2 crystals with identical grating periods were available, with a length of 20 mm and 30 mm. These crystals are divided into 8 separate sections, each with a different grating period.

The PPLN crystal is placed in an oven (Figure 3), which has two reasons. PPLN crystals can be damaged by high power green radiation. Due to the high gain in the crystal and the high laser power, frequency doubling of the pump to 532 nm (green light) takes place as well, in addition to OPO conversion. With the crystal at an elevated temperature, photo-refractive damage can be suppressed. Secondly, a change in crystal temperature changes the wavelength of the OPO output.

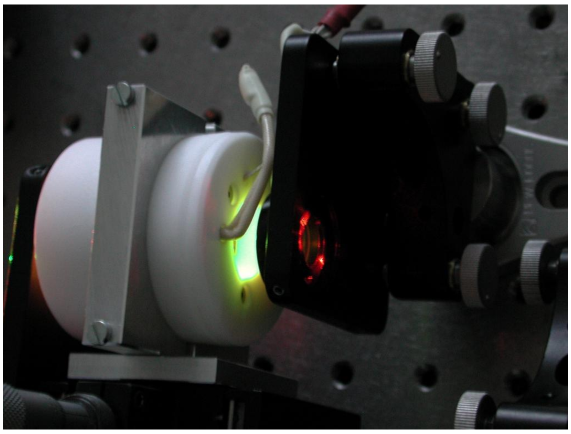

Figure 3 PPLN crystal emitting green light placed in oven with white Teflon casing.

Based on the results of Arisholm [3] we decided to use a crystal temperature of 190°C in our experiments as previously described. The tuning curve of the PPLN OPO, when kept at a temperature of 190°C and pumped with 1.064 µm, is drawn in Figure 4. The vertical lines show the 8 crystal periods of the two crystals we have acquired.

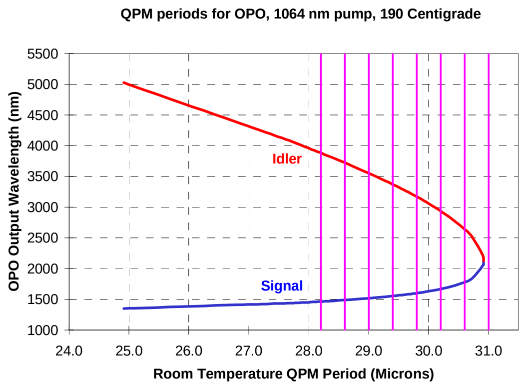

Figure 4 Required PPLN period for different wavelengths

In Table 5 the wavelength range for the different grating periods (with grating period specified at room temperature RT) of the PPLN crystal is given at 100°C (about the lowest crystal temperature found in our literature survey), 190°C and 220°C (maximum oven temperature).

Table 5 Wavelength range of PPLN crystal.

pump (nm)	RT period (µm)	Signal (nm) 100°C	190°C	220°C	Idler (nm) 100°C	190°C	220°C
1064	28.20	1447	1466	1474	4020	3880	3825
1064	28.60	1468	1490	1500	3870	3722	3661
1064	29.00	1491	1519	1531	3715	3552	3488
1064	29.40	1519	1555	1571	3552	3370	3297
1064	29.80	1553	1601	1625	3379	3172	3082
1064	30.20	1597	1669	1707	3187	2935	2825
1064	30.60	1658	1780	1880	2969	2645	2451
1064	31.00	1756	*	*	2700	*	*

**: no phase matching possible with this period above ~175°C*

With the pump laser and the PPLN crystal a laser was built (see Figure 5). A linear cavity design was used.

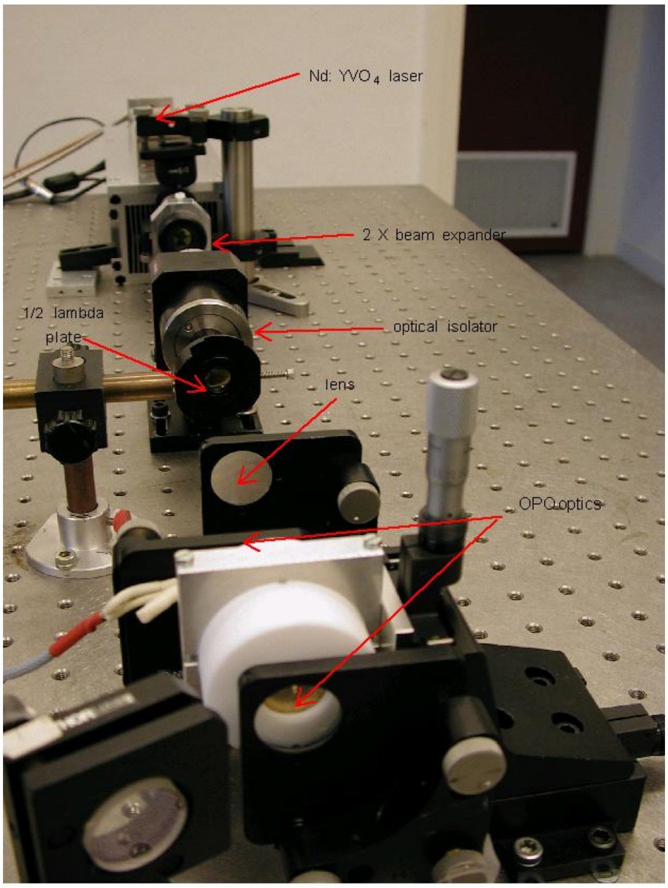

Figure 5   Overview laser on bread board

The pump laser beam diameter is increased to approx. 2 mm with a beam expander. An acousto-optic modulator is then used for modulation of the pump pulse train (not shown in Figure 5). Next, the pump laser beam goes through an optical isolator, so that reflections from optical components further on cannot damage the pump laser or the beam expander. A $1/2\lambda$ wave plate is used to adjust the polarisation of the pump laser beam. Non-linear generation in the PPLN crystal only occurs for a single linear polarisation. A lens with a focal length of 100 mm or 150 mm focuses the pump laser beam in the centre of the PPLN crystal. The crystal is placed in a linear cavity. The input coupler (first mirror of cavity) has a high transmission for the pump (1064 nm) and a high reflection for the generated signal. The output coupler (second mirror of the cavity) has a reflection of about 15% to 20% for signal and idler and approx. 10% for the pump. Appropriate band pass filters after the cavity can be used to separate the pump, signal and idler wavelengths.

According to the manufacturer (Deltronic), the maximum allowed power density on the PPLN crystal surface is 300 MW/cm^2. With the F=100 mm lens the power density in the focus is (with a 20 kHz rep-rate, 100 µJ energy and 8.2 ns pulse length): 275 MW/cm^2, close to the maximum power density. However, this is not on the surface, but inside the PPLN crystal, in which damage thresholds are usually much higher. Even so, care must be taken that the laser is not focused on crystal surfaces, especially with the F=100 mm lens.

The 30 mm PPLN OPO has been tested with two different lenses, with a focal length of 100 mm and 150 mm. The temperature of the 30 mm long crystal was kept at 190°C for all experiments unless mentioned otherwise. In Figure 6 the generated idler output for these two situations are shown at 20 kHz laser pump rep-rate as function of pump power.

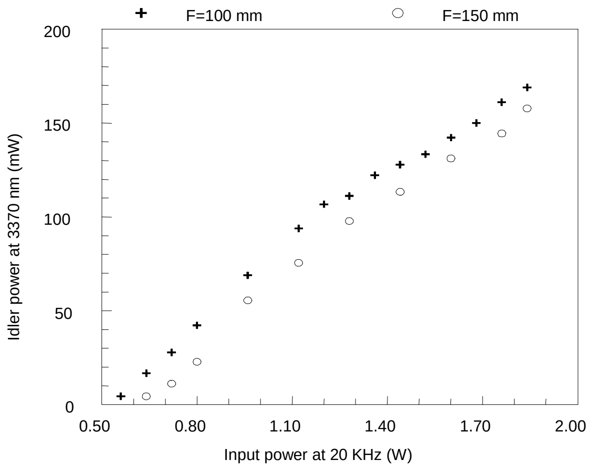

Figure 6 Laser output at 3370 nm (29.4 µm period and 190 C).

The input power in Figure 6 is the actual power entering the input coupler of the OPO, and about 80% of the output of the laser. The 3374 nm idler power is corrected for the losses of a long-wave-pass filter (10%), separating the idler from the pump and the signal. In addition to the idler power at 3374 nm, also the signal power at 1555 nm was measured. The results with the *F*=100 mm lens can be seen in Figure 7. At present, it is unclear why the two curves start to deviate above an input power of 1.2 W.

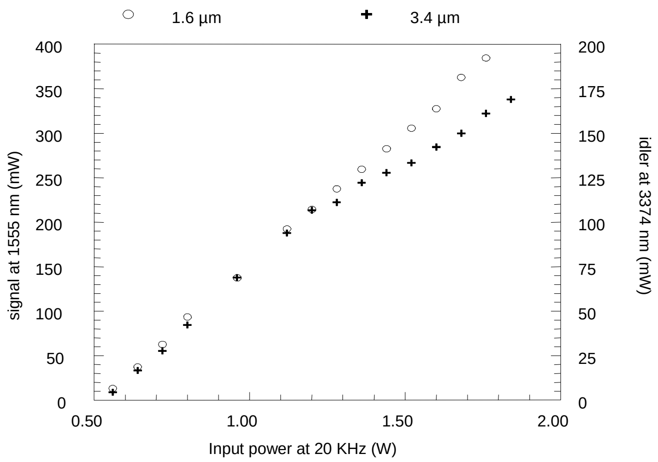

Figure 7 L*aser output for F=100 mm.*

The threshold pump laser power is approximately 0.5 W (at 20 kHz) or 25 µJ. If we use the measured focus diameter of 118 µm, we arrive at a threshold energy density of 0.23 J/cm^2, and a threshold power density of 27.9 MW/cm^2. The power efficiency is 8.8% (idler only) and the slope efficiency is 15% (idler only). In the table below, we compare the results with the values found in the literature review.

Table 6 TNO laser ccompared with literature values.

Property	TNO laser	Literature
Threshold energy density	0.23 J/cm^2	0.15-0.21 J/cm^2
Threshold power density	27.9 MW/cm^2	4.5-18 MW/cm^2
Power efficiency (idler)	8.8%	7.5-13%
Slope power efficiency (idler)	15%	11-22%

The efficiencies compare very well with the literature [4-11]. The threshold energy and power density, however, are higher than any literature value found during our literature review, but this can be attributed to low reflection for the signal beam at the output coupler. Also these values critically depend on the focus diameter, which was hard to measure with our current set-up. The power efficiency and slope power efficiency measurements are more straightforward and reliable, and assure us that we have built a state-of-the-art mid-IR laser.

To further increase the average power of the laser and therefore simultaneously increase the jam to signal ratio we must increase the pulse frequency. However, this result in lower pump pulse energy and increased pump pulse length, resulting in lower peak powers (see Table 4). In Table 7 the results of the output power measurements at higher rep-rates is shown.

Table 7 Output at higher rep-rates (F=100 mm).

Pulse frequency (KHz)	Input power (W)	Signal energy/power (1555 nm) (µJ)	(mW)	Idler energy/power (3374 nm) (µJ)	(mW)
20	1.88	19	380	7.90	158
22	2.00	17.4	382	7.36	162
24	2.12	16.7	400	6.96	167
26	2.24	15.7	408	6.46	168
28	2.36	14.6	410	6.07	170
30	2.48	14.0	420	5.33	160

Although above 20 kHz the pulse energy decreases, there is an increase in average power for the idler up to about 28 kHz.

3.1 4 micron generation

For DIRCM applications it is very important to generate jam power in the 3-5 µm band. It is of interest how far we can push the system to generate as much power as possible and to emit jam wavelength for the largest wavelength range as possible. Of special interest is to know how closely we can approach the 5 micron wavelength. With the current grating periods and for a crystal temperature of 190°C we can reach at most 3866 nm. In principle, we could use lower crystal temperatures, thus increasing the maximum wavelength, but this will decrease the lifetime of the crystal, according to literature reports [12]. In the Table 8 and Figure 8 we have plotted the generated jam power as function of the wavelength.

Table 8 Idler output power with 1.88 W pump input power (20 kHz) for grating periods of 28.2, 28.6, 29.0 and 29.4 µm for crystal temperature of 190°C.

Idler wavelength (nm)	Grating period (µm)	Measured power idler (mW)	Photon number
3866	28.2	131	$2.55.10^{18}$
3697	28.6	150	$2.79.10^{18}$
3541	29.0	153	$2.73.10^{18}$
3374	29.4	158	$2.68.10^{18}$

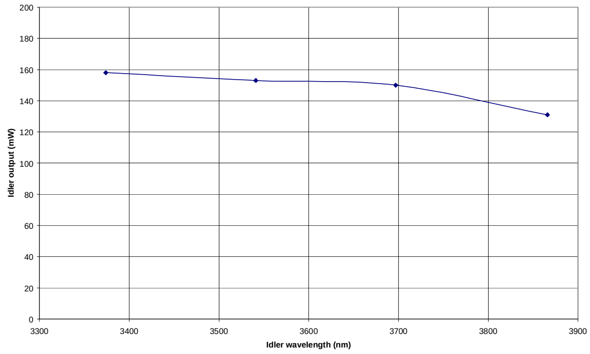

Figure 8 Idler output power with 1.88 W pump input power (20 kHz) for grating periods of 28.2, 28.6, 29.0 and 29.4 µm for crystal temperature of 190°C.

The power decreases for longer idler wavelengths. Although the PPLN crystal absorption increases for longer wavelength, this is not an absorption effect since the photon number increases at first. We notice a sudden drop for the 28.2 µm period, which seems larger than expected for a gradual increase in PPLN absorption as function of wavelength. A possible explanation is that there is a variation in the transmission of the long-wave pass filter, used to separate the idler from the pump and signal, which should be further looked into.

3.2 2 micron generation

With the longest period of the PPLN crystal (31.0 µm) it is possible to have a signal (2050 nm) and idler (2212 nm) with almost identical wavelength at approx. 175°C (see Figure 9).

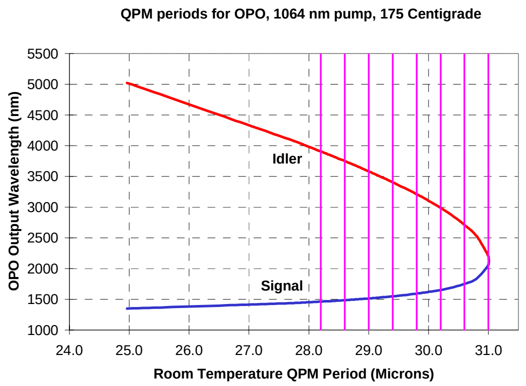

Figure 9 Wavelength with PPLN crystal at 175° C.

The total output (signal+idler) from the OPO was measured at different temperatures with 1.88 W input power at 20 kHz rep-rate and *F*=150 mm, as depicted in Figure 10.

As expected, above about 175° C the output rapidly decreases because the grating periods become too long for phase matching.

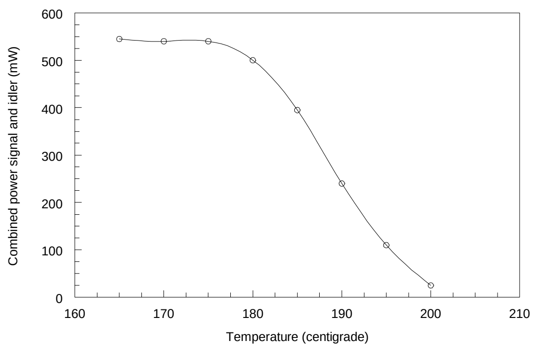

Figure 10 Output signal and idler with 31.0 µm grating period.

Using the knife-edge method [13], the beam quality parameter (M^2) of the idler output of the laser was measured as well (for which a grating period of 29.4 µm was used). The idler beam (3.37 µm) was collimated with a CaF_2 lens (*F*=95 mm) and focused with a germanium lens (*F*=50 mm). The transmission of the germanium lens, which was coated for 10.6 µm is only about 50% for the idler wavelength. This reduces the power on the detector. The most sensitive range of the thermopile detector is 100 mW full scale. The beam focus measurements were even less reliable than the previous beam focus measurements of the pump laser. This time we only had approx. 50 mW power available for the knife-edge measurements and at the same time we had to measure with a thermopile detector with an inherent slow response.

For a focal length of 50 mm the diameter of the focus for a laser with M^2=1 would be 45 µm. The smallest focus diameter that was measured was 124 µm, resulting in a M^2 of 2.5. With an accuracy of 40 µm of the focus diameter the M^2 would be 2.5±0.9.

Because of the small depth of focus (DOF) the knife must be placed almost exactly at the focus position or a too large diameter will be measured. If the knife-edge were placed 0.5 mm from the focus position the measured focus diameter would be about 1.5 times larger. This would mean that the calculated M^2 would be about 1.5 times smaller and would be between 1.1 and 2.3. The set-up used to measure the beam quality needs to be improved for more accurate determination of the beam quality parameter M^2.

3.3 Jamming to signal calculation

We can calculate the jamming to signal ratio, that we can achieve with our current laser. We assume we have 160 mW of jam power in the whole wavelength range from 2 to 4 microns, although at approx. 2 µm we will have a boost in output power as the signal and idler wavelengths are then identical. This is less than the operational required jam power of 1 Watt with 1 mrad beam divergence or 4 Watt with 2 mrad beam divergence. To compensate for the reduced laser power we will more tightly focus our beam. Since the laser will be used in laboratory and field experiments, to study infrared countermeasure techniques, we can more easily pin point the beam to the target in comparison to an operational system. We will use an optical output beam diameter of either 15 mm or 25 mm, and we assume that there will be an optical loss of 30% in lenses and windows. Based on these assumptions the *J/S* ratio is calculated and plotted in Figure 11 for an optical aperture of 15 and 25 mm, respectively, as function of beam divergence. The lowest beam divergence corresponds to a jammer wavelength of 2 micron, the largest beam divergence corresponds to a jammer wavelength of 4 micron.

We can see that for aircraft signatures in the range from 10 up to 1000 W/sr and for an optical aperture of 15 mm or 25 mm we can maintain a *J/S* ratio of more than 23 dB for all conditions. The lowest *J/S* ratio is achieved for the highest aircraft thermal signature of 1000 W/sr and for a wavelength of 4 micron. In this case, we reached a *J/S* ratio of 23 dB and 27 dB for an optical aperture of 15 and 25 mm respectively. This is below our target figure of 30 dB.

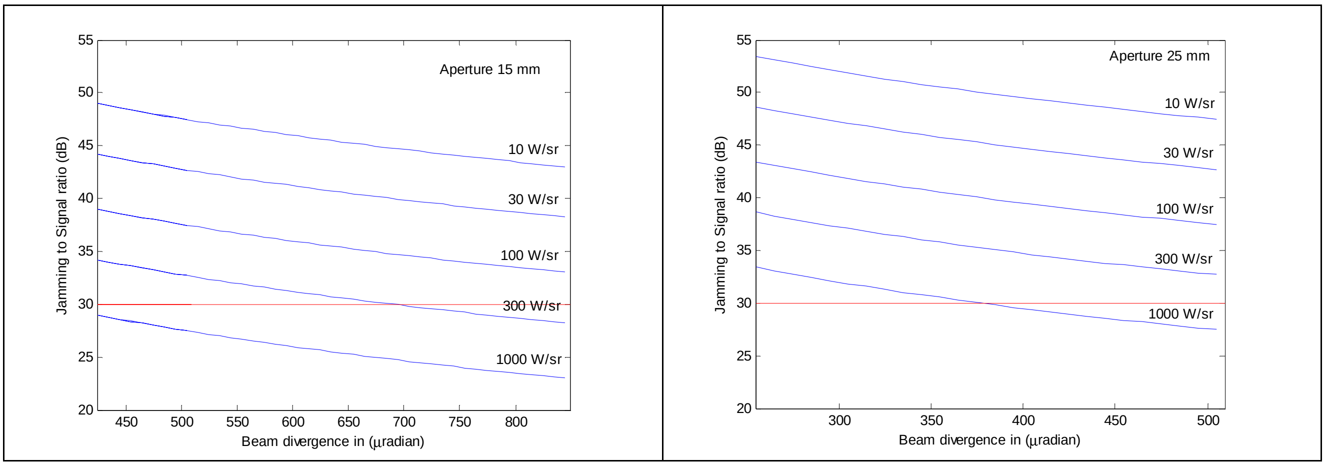

Figure 11 (Left) Laser power 0.16 Watt, optical transmission 0.7, M^2=2.5. Beam divergences used that correspond with an aperture of 15 mm for a wavelength varying between 2 and 4 µm; Laser power 0.16 Watt, optical transmission 0.7, M^2=2.5. Beam divergences used that correspond with an aperture of 25 mm for a wavelength varying between 2 and 4 µm.

3.4 Laser jam pattern characterisation

To be able to jam IR missiles a modulation pattern must be generated. We used an acousto-optic modulator AOM.

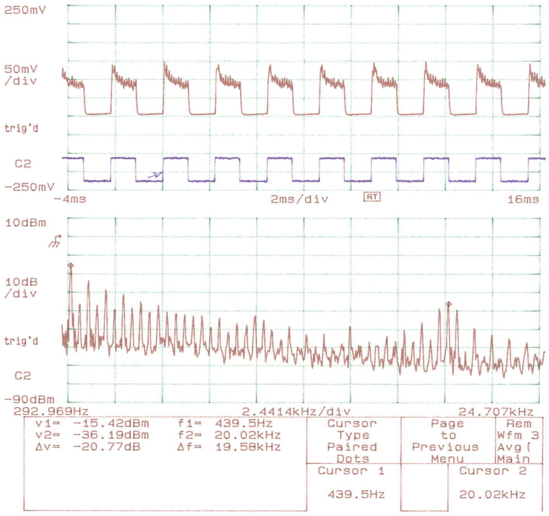

Figure 12 Modulated laser output (top curve), modulation pattern (middle curve) and Fourier spectrum of modulated laser output (bottom curve) .

When an RF frequency is put on the AOM, it generates a bulk acoustic wave in the modulator crystal. The laser beam will be diffracted at the induced grating and will be deflected to another direction. The AOM can diffract about 90% of the laser energy. We have placed the AOM behind the beam expander. If no RF pulse is fed into the AOM the pump laser pulse will travel undeflected by the AOM into the OPO cavity and signal and idler wavelengths will be generated. If an RF pulse is fed into the modulator, 90% of the pump laser pulse will be deflected and it will not reach the OPO cavity, but it will be dumped into a beam dump. Only 10% of the pump laser beam reaches the OPO cavity, but since this power is below the threshold for oscillation no signal and idler wavelengths will be generated. Therefore, a 100% modulation of the idler wavelength (the jam laser wavelength) can be achieved. The RF-power to the AOM can be modulated by a 5 V TTL input signal up to several MHz.

To measure the modulated laser output (idler OPO output) an uncooled 1 GHz HgCdTe detector was used. This detector was placed after the long-wave pass filter used to separate the idler wavelength from the pump and signal wavelengths. The AOM was modulated with a 440 Hz square wave (see the middle curve of Figure 12). The laser was working at maximum power at a rep-rate of 20 kHz. The output from the HgCdTe detector was filtered (0.1 Hz-10 kHz) and amplified and is shown in Figure 12 (top curve). We recognise the square modulation pattern. When the laser is on (top of the curves of the top curve), we can almost observe the individual pump laser pulses. It also appears as if the power drops within a half period of the modulation square wave, but this is an artefact since the detector was AC coupled. In addition to the 440 Hz signal (and many higher harmonics), the 20 kHz rep-rate of the laser is also visible in the FFT spectrum (bottom curve in Figure 12). Despite the fact that the HgCdTe detector signal was filtered with a bandpass filter between 0.1 Hz and 10 kHz, some 20 kHz still passed.

We have thus successfully shown that IR jamming pulses with various patterns can effectively be created using the AOM modulator.

4. CONCLUSIONS

In this project, a tuneable mid-infrared laser source was built. The system was composed of commercial of the shelf components. The power efficiency (8.8%) and slope power efficiency (15%) measurements indicate that our laser source can compete with state of the art mid-IR laser sources (see Table 6).

At present, wavelengths in the range of 1.5 to 3.9 μm can be generated. The maximum wavelength that can be generated is limited by the grating period in our PPLN crystal and by the fact that the crystal has to be kept at elevated temperatures (>180°C) to avoid permanent photorefractive damage. Another crystal with different grating periods would allow us to increase the maximum jammer wavelength. However, above 4 μm the non-linear PPLN crystal starts to absorb the generated radiation, thus reducing the idler output power levels.

Power levels vary across the wavelength range from 400 mW at 1.5 μm to 130 mW at 3.9 μm. The output power can be further increased with a more powerful pump laser. The current power levels allow us to successfully perform ground-based seeker jamming experiments. We have calculated that for an optical aperture of 15 mm and 25 mm we can reach a *J/S* ratio of more than 23 dB in all situations for aircraft signatures in the range of 10-1000 W/sr.

We have also shown that with incorporation of an acousto-optic modulator we can generate all kinds of complicated jam sequences.

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