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Case Number: T 0412/17 - 3.4.03

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Language of the proceedings: EN

Title of invention:
CONTROL OF RELAXATION OSCILLATIONS IN INTRACAVITY OPTICAL PARAMETRIC OSCILLATORS

Applicant:
The University Court of the University of St Andrews

Headword:

Relevant legal provisions:
EPC Art. 56

Keyword:
Inventive step - (no)

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Catchword:

Beschwerdekammern

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Case Number: T 0412/17 - 3.4.03

D E C I S I O N
of Technical Board of Appeal 3.4.03
of 18 February 2020

Appellant: (Applicant)	The University Court of the University of St Andrews College Gate North Street St Andrews, Fife KY16 9AJ (GB)
Representative:	Walker, Stephen Lincoln IP 9 Victoria Street Aberdeen AB10 1XB (GB)
Decision under appeal:	**Decision of the Examining Division of the European Patent Office posted on 29 July 2016 refusing European patent application No. 09784820.4 pursuant to Article 97(2) EPC.**

Composition of the Board:

Chairman	G. Eliasson
Members:	M. Stenger
	G. Decker

Summary of Facts and Submissions

I. The appeal concerns the decision of the Examining Division to refuse European patent application No. 09784820 for lack of inventive step. The refused application is based on International application No. WO 2010/013003 A2.

II. Reference is made to the following documents:

D2: Turnbull G. et al.: "Transient Dynamics of CW Intracavity Singly Resonant Optical Parametric Oscillators", IEEE Journal of Quantum Electronics, Vol. 35, No. 11, pages 1666 - 1672, November 1999, ISSN: 0018-9197, XP000902533

D5: Lee D.-H. et al.: "Self-injection-locking of a CW-OPO by intracavity frequency-doubling the idler wave", OPTICS EXPRESS, Vol. 5, No. 5, pages 114 - 119, August 1999, XP9137201

III. The appellant requested in the grounds of appeal that the contested decision be set aside and that a patent be granted according to a main request or according to one of auxiliary requests 1 to 7. All requests were filed with the grounds of appeal.

IV. In a communication preparing the oral proceedings, the Board expressed its preliminary opinion that the skilled person, using their common general knowledge, would insert an additional optical non-linear element into any of the cavities of an optical parametric oscillator (OPO) in order to enhance the wavelength range of the OPO (see point 6.3 of that communication). The Board further argued that such an insertion would inevitably introduce an additional non-linear loss reducing relaxation oscillations.

V. The appellant did not reply thereto in substance. Instead, the representative announced with letter dated 14 February 2010 that he would not be attending the oral proceedings scheduled for 18 February 2020. Oral proceedings were held in absence of the appellant.

VI. Claim 1 of the main request has the following wording (labeling (m), (a) added by the Board):

(m) *An intra-cavity optical parametric oscillator including:*

a gain medium (14) for generating a pump wave; and

a non-linear material (24),

wherein the gain medium (14) and the non-linear material (24) are located within a pump cavity and the non-linear material (24) is located within a down-converted wave cavity which is coupled to the pump cavity, so that, in use, a pump field is established in the pump cavity and parametric frequency conversion of the pump wave in the non-linear material (24) generates a signal wave and an idler wave, and at least one of the signal wave and the idler wave is resonant in the down-converted wave cavity so as to provide a down-converted resonant field in the down-converted wave cavity, and

(a) *wherein the intra-cavity optical parametric oscillator further includes means (30) for providing a non-linear loss for suppressing relaxation oscillations.*

VII. Claim 1 of auxiliary request 1 differs from claim 1 of the main request in that feature (a) is replaced by feature (a') and in that it further includes at its end features (b), (c) and (d) which are claimed alternative to each other as follows:

(a') *wherein the intra-cavity optical parametric oscillator further includes means (30) for providing a non-linear loss for suppressing relaxation oscillations, which means (30) are:*

(b) *located in the pump cavity and configured to generate a second harmonic of radiation in the pump cavity at a frequency of the pump wave, or*

(c) *configured to generate a second harmonic of the down-converted resonant field,* or

(d) *configured to frequency mix the pump field and the down-converted resonant field.*

VIII. Claim 1 of auxiliary request 2 differs from claim 1 of auxiliary request 1 in that alternative feature (b) is deleted.

IX. Claim 1 of auxiliary request 3 has the following wording (labeling (m'), (a''), (e),... added by the Board):

(m') *An intra-cavity optical parametric oscillator including:*

a laser gain medium (14) for generating a pump wave;

a non-linear material (24) for generating down converted coherent radiation in response to a pump wave, the down converted radiation comprising a signal wave and an idler wave;

two coupled optical cavities, these being a pump-wave cavity for resonating the pump wave and a down converted wave cavity for resonating the signal wave and/or the idler wave, wherein the non-linear material (24) and the laser gain medium (14) are located in the pump-wave cavity and the non-linear material (24) is also located in the down converted wave cavity, and

(a'') *optical means (30) configured to provide a non-linear loss for suppressing relaxation oscillation, characterised in that:*

(e) *the optical means (30) for providing a non-linear loss are configured to provide an instantaneous non-linear loss, and are:*

(b') *located in the pump-wave cavity and configured to generate a second harmonic of the intra-cavity radiation at the pump wave frequency, or*

(c') *located in the down converted wave cavity and configured to generate a second harmonic of the down converted coherent radiation, or* (d') *located in a shared part of both the pump-wave cavity and the down converted wave cavity and configured to generate radiation by sum frequency mixing of intra-cavity radiation at the pump laser frequency and intra-cavity radiation at the resonant down converted radiation frequency.*

X. Claim 1 of auxiliary request 4 differs from claim 1 of auxiliary request 3 in that feature (b') is deleted.

XI. Claim 1 of auxiliary request 5 has the following wording (labeling (m''), (a) added by the Board):

(m'') *An intra-cavity optical parametric oscillator including:*

a gain medium (14) for generating a pump wave;

a non-linear material (24);

first, second and third mirrors (16, 18, 26); and

a beam splitter (22),

wherein the first and second mirrors (16, 18) define a pump cavity,

wherein the beam splitter (22) is located in the pump cavity,

wherein the second and third mirrors (18, 26) and the beam splitter (22) together define a down-converted wave cavity, *wherein the gain medium (14) is located in the pump cavity between the first mirror (16) and the beam splitter (22) and the non-linear material (24) is located in both the pump cavity and the down-converted wave cavity between the beam splitter (22) and the second mirror (18) so that, in use, a pump field is established in the pump cavity and parametric frequency conversion of the pump wave in the non-linear material generates a signal wave and an idler wave, and at least one of the signal wave and the idler wave is resonant in the down-converted wave cavity so as to provide a down-converted resonant field in the down-converted wave cavity, and*

(a) *wherein the intra-cavity optical parametric oscillator further includes means (30) for providing a non-linear loss for suppressing relaxation oscillations.*

XII. Claim 1 of auxiliary request 6 differs from claim 1 of auxiliary request 5 in that feature (a) is replaced by feature (a') as defined above and in that it includes at its end features (b), (c) and (d) claimed as alternatives and as defined above.

XIII. Claim 1 of auxiliary request 7 differs from claim 1 of auxiliary request 6 in that feature (b) is deleted.

XIV. The relevant arguments of the appellant may be summarised as follows:

(a) The non-linear variations in the intra-cavity power and in the idler field power represented gains provided by the two crystals. They could thus not be considered as providing a non-linear loss (Grounds of appeal, point 1.2.2).

(b) Document D2 suggested specific techniques for suppressing relaxation oscillations in an intra-cavity OPO. The skilled person would have no motivation to seek alternative techniques to solve that problem (grounds of appeal, page 5 except the last paragraph). Further, the other documents mentioned in the contested decision would not anticipate or suggest the provision of a non-linear loss for suppressing relaxation oscillations in an intra-cavity OPO (see the various points of the grounds of appeal relating to inventive step).

Reasons for the Decision

1. The appeal is admissible.

2. The application

The application relates to intra-cavity optical parametric oscillators (OPOs), i.e. to OPOs where the non-linear material responsible for the parametric frequency conversion is located in the pump wave cavity. The purpose of the application is to provide an intra-cavity OPO with a stable output by reducing or eliminating relaxation oscillations (page 4, lines 25 to 28 of the published application).

3. Document D2

Document D2 is an academic article relating to the study of relaxation oscillations in intra-cavity optical parametric oscillators (abstract). Possible techniques to suppress such relaxation oscillations are discussed (part V. C. *Implications to Stable CW ICSRO Operation*).

4. Preliminary remark concerning *additional non-linear loss*

As mentioned above, the invention aims at reducing relaxation oscillations in order to make the output of the OPO more stable (page 4, lines 25 to 28 of the published application).

The application indicates in a very general manner that this problem can be solved by *including means for producing a non-linear loss in addition to that provided by normal operation of the OPO itself* (page 4, lines 25 to 27 of the published application).
No details are given in the application as a whole as to the *magnitude*, *shape* or *power dependence* of the additional non-linear loss that is required to achieve a reduction of relaxation oscillations. The *amount* of the reduction achieved by the additional non-linear loss is not indicated in the application, either.

It must be concluded that *any* means producing some non-linear loss in an intra-cavity OPO in addition to the non-linear loss provided by normal operation of the OPO have to be considered to correspond to *means for providing non-linear loss for suppressing relaxation oscillations* within the meaning of the application.

5. Main request and auxiliary requests 1 to 7

5.1 Features (m), (m') and (m'')

The first features (m), (m') and (m'') of the independent claims of all requests all have a slightly different wording and a slightly different level of detail. In substance, however, they all essentially define a standard intra-cavity optical parametric oscillator as for example disclosed in D2.

Feature (m''), which explicitly mentions some structural elements of the cavities, exhibits the highest level of detail of all these features. In substance, feature (m'') is more specific than each of features (m) and (m') and thus falls under the wording of each of these features.

In the wording of feature (m''), D2 discloses (see generally Figure 1):

An intra-cavity optical parametric oscillator (see title) including:

a gain medium (*$NdYVO_4$*) for generating a pump wave;

a non-linear material (*PPLN*);

first, second and third mirrors (*M1, M2, M3*); and

a beam splitter (*BS*),

wherein the first and second mirrors (*M1, M2*) define a pump cavity (*Laser Cavity*), wherein the beam splitter (*BS*) is located in the pump cavity (*Laser Cavity*),

wherein the second and third mirrors (*M2, M3*) and the beam splitter (*BS*) together define a down-converted wave cavity (*Signal cavity*),

wherein the gain medium ($NdYVO_4$) is located in the pump cavity between the first mirror (*M1*) and the beam splitter (*BS*) and the non-linear material (*PPLN*) is located in both the pump cavity and the down-converted wave cavity between the beam splitter (*BS*) and the second mirror (*M2*) so that, in use, a pump field is established in the pump cavity and parametric frequency conversion of the pump wave in the non-linear material generates a signal wave and an idler wave, and the signal wave is resonant in the down-converted wave cavity so as to provide a down-converted resonant field in the down-converted wave cavity (see abstract and page 1667, right-hand column, second paragraph).

That is, D2 discloses feature (m'') in its entirety. Since features (m) and (m') differ from feature (m'') in substance only in that they are less detailed as mentioned above, D2 also discloses these two features.

5.2 Preliminary remark concerning feature (e)

Feature (e) appears only in the independent claims of auxiliary requests 3 and 4 and always in combination with features (c') and (d'). Since second harmonic generation as defined in these latter features is an *instantaneous* effect, feature (e) is in substance implied by any of features (c') and (d'). Therefore, feature (e) does not need to be addressed individually for the purpose of assessing novelty and inventive step.

5.3 Feature (a)

The *thermal lensing* mentioned in D2 is caused by the two gain media used (i.e. the NdYVO4 and PPLN crystals), as argued by the appellant (see section XIV. (a) above). Both gain media are required during normal operation of the OPO. The effect of thermal lensing can therefore not be regarded as representing a non-linear loss *additional* to the one provided by the normal operation of the OPO within the meaning of the application (see point 4 above).
It follows that D2 does not disclose feature (a), contrary to point 6.2 of the communication preparing the oral proceedings and expressing the preliminary opinion of the Board.

5.4 Distinguishing features

Thus, the subject-matter of the independent claims of the different requests respectively differs from D2 in substance (for feature (e) see point 5.2 above) by various combination of features (a), (a'), (a''), (b), (b'), (c), (c'), (d) and (d') as follows:

Request	Distinguishing features
Main request:	(a)
Auxiliary request 1:	(a') and (b) or (c) or (d)
Auxiliary request 2:	(a') and (c) or (d)
Auxiliary request 3:	(a'') and (b') or (c') or (d')
Auxiliary request 4:	(a'') and (c') or (d')
Auxiliary request 5:	(a)
Auxiliary request 6:	(a') and (b) or (c) or (d)

Auxiliary request 7: (a') and (c) or (d)

5.5 Inventive step

5.5.1 Features (a), (a') and (a'')

Starting from D2, the skilled person would certainly have tried to solve the problem of suppressing relaxation oscillation. The arguments of the appellant concern this particular problem (see point XIV.(b) above).

In addition to and independent of the suppression of relaxation oscillations, however, the skilled person would also always have considered other problems in order to generally improve an intra-cavity OPO like the one disclosed in D2.

One of these other problems concerns the general desire to increase the interaction (length) between the pump wave and the non-linear medium.
Another one of these other problems is the generally desired enhancement of the range of wavelengths emitted by the OPO in order to obtain output light with desired wavelength characteristics.

In relation to these other problems and as already noted in the Board's preliminary opinion (see point 6.3 thereof), it was generally known to the skilled person well before the priority date of the present application that a plurality of different non-linear crystals in a *stacked* or *cascaded* configuration could be used to obtain output light with a plurality of different (desired) wavelengths. The same applies to the use of one non-linear crystal with a plurality of different gratings, as also expressed in the Board's communication preparing the oral proceedings.

That is, the skilled person would have considered in a straightforward manner to add an additional optical non-linear element to any kind of OPO, including the one disclosed in D2, for example to enhance the wavelength range of this OPO.

Such an additional optical non-linear element would inevitably introduce an *additional non-linear loss*, which then would *reduce relaxation oscillations* at least within the very general meaning as used in the present application (see point 4 above).

Thereby, the skilled person would have incorporated any of the features (a), (a') and (a'') into the system of D2 in view of their common general knowledge.

5.5.2 Features (b), (b'), (c) and (c')

Further, it was also generally known that the plurality of different non-linear crystals or gratings in such a stacked or cascaded arrangement could be chosen such that different non-linear effects were combined in order to obtain emitted light with the desired wavelength characteristics.
Second and third harmonic generation is (and was at the priority date of the present application) the best established optical non-linear effect. The skilled person would thus readily have considered to use optical parametric oscillation together with second or third harmonic generation to obtain emitted light with the desired wavelength characteristics.
An example for such a combination of different non-linear effects is disclosed in D5 where a by-three

division of the optical frequency of the input light is implemented using OPO and second harmonic generation simultaneously (see abstract).

When considering to add an optical non-linear element to an intra-cavity OPO, the skilled person would have inserted the additional non-linear element in any of the cavities of the OPO, depending only on the wavelengths of the light to be converted in order to obtain the desired output wavelength characteristics.

Doing so, the skilled person would in a straightforward manner and using their common general knowledge further have incorporated any of features (b), (b'), (c) and (c') into the system of D2.

5.5.3 Summary and conclusion with respect to inventive step

D2 discloses features (m), (m') and (m'').

Starting from D2, the skilled person would have incorporated any of features (a), (a') and (a'') using their common general knowledge (see point 5.5.1 above).

They would thereby have arrived at the subject-matter of the independent claims of the main request and of auxiliary request 5 (see point 5.4 above) without the exercise of an inventive step within the meaning of Article 56 EPC.

Starting from D2, the skilled person would further have incorporated any of features (b), (b'), (c) and (c') using their common general knowledge (see point 5.5.2 above). As noted above (see point 5.2), the incorporation of feature (c') would imply the incorporation of feature (e) as well.

They would thereby, for each of the independent claims of auxiliary requests 1 to 4 and 6 to 7, have arrived at the subject-matter of at least one of the alternatives claimed therein (see point 5.4 above).

Thus, the subject-matter of each of the independent claims of the main request and of auxiliary requests 1 to 7 lacks an inventive step according to Article 56 EPC in view of D2 and the common general knowledge of the skilled person.

6. None of the requests fulfils the requirements of the EPC. Thus, the appeal must fail.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar: The Chairman:

Beschwerdekammern des Europäischen Patentamts · Boards of Appeal of the European Patent Office · Chambres de recours de l'Office européen des brevets

S. Sánchez Chiquero G. Eliasson

Decision electronically authenticated