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**DECISION**  
of 12 November 1996

**Case Number:** T 0899/93 - 3.4.1

**Application Number:** 88303282.3

**Publication Number:** 0287332

**IPC:** H01S 3/23

**Language of the proceedings:** EN

**Title of invention:**  
Optical amplifier

**Applicant:**  
BRITISH TELECOMMUNICATIONS public limited company

**Opponent:**  
-

**Headword:**  
Optical amplifier/BRITISH TELECOMMUNICATIONS

**Relevant legal provisions:**  
EPC Art. 56

**Keyword:**  
"Inventive step - yes (after amendments)"

**Decisions cited:**  
-

**Catchword:**  
-



Case Number: T 0899/93 - 3.4.1

**D E C I S I O N**  
of the Technical Board of Appeal 3.4.1  
of 12 November 1996

**Appellant:** BRITISH TELECOMMUNICATIONS public limited  
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**Decision under appeal:** Decision of the Examining Division of the  
European Patent Office dated 10 May 1993 refusing  
European patent application No. 88 303 282.3  
pursuant to Article 97(1) EPC.

**Composition of the Board:**

**Chairman:** G. D. Paterson  
**Members:** R. K. Shukla  
U. G. O. Himmler

## Summary of Facts and Submissions

I. European patent application No. 88 303 282.3 was refused by a decision of the Examining Division on the ground that the subject matter of independent claims 1 and 8 lacked an inventive step in view of the prior art document:

D1: Applied Physics letter, vol. 45 no. 12, December 1984, pages 1314 to 1316.

Also the following prior art documents are discussed in the decision of the Examining Division:

D2: EP-A-0 174 729;

D5: IEEE Journal of Quantum Electronics, vol. Q-19, no. 8, August 1983, pp. 1302-1311, and

D6: Colloquium on heterostructure optoelectronic and high speed devices, paper 6, 13 November 1984, "Laser diode amplifiers" by M. S. Demokan.

II. The Applicant lodged an appeal against the above decision and requested the grant of a patent based on an amended set of claims.

III. In an annex to a summons to oral proceedings, the Board informed the Appellant that after preliminary consideration, the claimed subject matter appeared to lack an inventive step having regard to documents D2 and D5.

IV. At the oral proceedings held on 12 November 1996, the Appellant filed amended pages of the description and claims, and requested the grant of a patent with the following text:

**Description:** pages 1, 1A, 4 and 8 as filed during the oral proceedings;  
pages 2, 5 and 6 as originally filed; and  
pages 3 and 7 as filed on 16 May 1992;

**Claims:** 1 to 16 as filed during the oral proceedings;

**Drawings:** as originally filed.

V. The independent claims of the above set of claims read as follows:

**Claim 1**

"A method of generating output pulses using a semiconductor laser amplifier of the type having a semiconductor medium exhibiting carrier density depletion, the method comprising the steps of:

- (a) applying a bias current to the laser amplifier less than the bias current required to induce lasing in the amplifier, the bias current establishing an internal carrier density within the amplifier;
- (b) exciting the amplifier with optical pulses of sufficiently high pulse energy that the excitation substantially completely depletes the established internal carrier density;

- (c) providing the excitation optical pulses with a time interval between pulses in excess of twice the time required for the amplifier internal carrier density to substantially recover from said depletion; wherein the excitation pulses have a duration of substantially less than said recovery time, and
- (d) taking the output of the amplifier in the period during which the established internal carrier density is being depleted."

**Claim 4**

"An optical pulse source comprising a semiconductor laser amplifier arranged in operation to generate output optical pulses having a peak power of at least 100mW in response to optical excitation, the amplifier exhibiting carrier concentration depletion in response to said excitation, and drive means optically coupled to the amplifier arranged in operation to generate optical excitation pulses and to apply a series of such excitation pulses to the amplifier, the drive means including means to provide a time interval between pulses in excess of twice the time required for the amplifier internal carrier density to substantially recover from said depletion, wherein the drive means is arranged to produce excitation pulses of sufficiently high pulse energy that the excitation substantially completely depletes the established internal carrier density, and wherein the drive means is such as to control the durations of said excitation pulses to be substantially less than the time the amplifier takes to recover from said depletion, thereby in use to generate said optical output pulses in the period during which the established internal carrier density is being depleted."

VI. In support of its view that the claimed subject matter involves an inventive step, the Appellant made essentially the following submissions.

The present invention is concerned with achieving a high power output from an optical semiconductor laser amplifier. At the time the present invention was made, those working in the field were concerned with the problem of pulse distortion, and nobody thought at that time that high power output could be obtained by increasing the interval between the pulses.

Document D1 is concerned with high speed modulation and switching and not with the generation of high output power pulses. Moreover, since the carrier concentration in the active area changes little over the pulse duration (page 1316), it follows that the input optical pulses do not substantially completely deplete the internal carrier density as in the present invention.

Although document D2 describes a semiconductor laser amplifier, the input power of the pulses is very low (i.e. in microwatts). Furthermore, the document does not disclose a pulsed input signal.

In document D5, it is disclosed on page 1309 that interpulse interference may occur. However, it is clear from Figure 7 that such interference does not significantly change the energy of the output pulses, but instead the pulse energy is influenced only for a small fraction of the pulse - about 5 ps - at the beginning of the pulse when the pulses are close together. Document D5 also teaches that in order to maintain a uniform output, a high data rate should be used so as to keep the inverted population at a low level. This is just the opposite of what the present invention proposes.

Document D6 is a simplified theoretical study of laser diode amplifiers. Figures 1 to 3 of the document show that the gain of the amplifier does not increase when the pulse separation is above about 3 ns. This separation is less than twice the time normally required for the amplifier internal carrier density to substantially recover from the depletion caused by the previous pulse.

### Reasons for the Decision

1. *Allowability of the amendments*

**Claim 1:**

In the application as filed all the claims relate to a "product". However, the description as filed is primarily concerned with operation of a laser amplifier so as to produce relatively high power output pulses (see page 1, lines 13 to 16; page 4, lines 7 to 8; page 6, lines 6, 7; Figure 3). It also follows from the original description that in the operation of the laser amplifier, the biasing current is below the threshold current for lasing, the output is taken during the period when the carrier density changes from a maximum value to a minimum value, and that the input pulses have a width (typically 40 ps) which is substantially less than the pulse repetition rate (typically 10 ns; see page 6, line 29 to page 7, line 14; page 5, lines 5 to 8; page 4, lines 25 to 27). Moreover, it follows from the original description (see the relationship between the peak output power and the pulse repetition rate on page 6; page 7, lines 3 to 4; page 8, lines 24 to 27) that the pulse repetition rate can be at least twice the recovery time.

**Claim 4:**

In the application as filed, claim 13 relates to an optical pulse source, the latter also forming the subject-matter of the amended independent claim 4. Moreover, in the application as filed a laser amplifier producing a peak output power of at least 100 mW is described (see Figure 4 ; page 6, line 36 to page 7, line 2, and page 7, lines 8 to 10). The remaining features of claim 4 correspond to the features of claim 1 discussed above.

The Board therefore finds that the amended claims 1 and 4 do not extend beyond the content of the application as filed (Article 123(2) EPC).

Description:

The description has been amended primarily for consistency with the claims as amended and therefore complies with the requirement of Article 123(2) EPC.

2. *Inventive step*

2.1 Claim 1

2.1.1 In the Board's view, document D2 represents the closest prior art and describes a semiconductor laser amplifier biased at a current below the threshold bias current for lasing (see page 2, lines 1 to 6; page 6, lines 28, 29; page 10, lines 30, 31 ). Also, since an optical signal is *amplified* in the laser structure, it follows that the semiconductor medium exhibits a depletion in carrier density when the signal is incident on the amplifier. There is however no disclosure in document D2 that the input signal is pulsed, and, consequently, there is no disclosure concerning pulse repetition rate in relation to recovery time of the carriers.

The method of generating optical pulses according to claim 1 is thus distinguished over the closest prior art in that

- (i) the time interval between the excitation pulses is in excess of twice the time required for the amplifier internal carrier density to substantially recover from the depletion;
- (ii) the excitation pulses have a duration of substantially less than the recovery time and
- (iii) the excitation pulses have sufficiently high energy to substantially completely deplete the carrier density established by the bias current.

It follows from the description of the invention (see, e.g., page 1, lines 13 to 16; pages 4, 5 and 6 ; page 7, line 2; and Figure 1) that the above distinguishing features enable relatively high power output pulses to be generated (up to peak output power of about 2.5 W).

- 2.1.2 Document D1, which was regarded as the closest prior art in the decision under appeal, is concerned primarily with high speed modulation and switching (greater than 1 GHz), and employs an average input power of 0.1 or 0.2 mW. The document also reports that at higher input power there was saturation in the gain and that at an average input power of 5mW, the gain was reduced to about 1 (see page 1315, left-hand column, last paragraph). On page 1316, left-hand column, it is stated that the carrier concentration changes little over the pulse duration. The Board agrees with the Appellant's submission that this disclosure implies that the pulse energy of the excitation pulses is not sufficiently high so as to completely deplete the carrier density, as in the method of the present

invention. Moreover, since at 5mW input power the gain of the amplifier is reduced to 1 (implying no amplification of the signal), in the Board's view, the skilled person concerned with generating relatively high power output pulses would not regard this document as relevant to his problem. Moreover, there is no hint in the document that by extending the time interval between the pulses above twice the recovery time, a higher output power can be achieved.

Document D5 reports the results of a theoretical investigation of travelling wave light amplification in a double heterostructure device. In the study involving a sequence of pulses as shown in Figure 7 (see page 1309, "C. Mutipulse Effects "), it is disclosed that the differences in output from various pulses in the sequence are caused by the slow pumping time in relation to pulse length and interpulse spacing, and that there is significant inversion recovery between the third and fourth pulses (see left hand column), the interpulse spacing between these pulses being the highest. Moreover, it follows from the disclosure in the right hand column that in theory, each input pulse generates an individual output pulse based entirely on the inverted population levels at the beginning of the pulse, and that in practice as the pumping processes generating the inverted population are much slower than the collision processes, there is insufficient time between pulses to build up signal -free inverted population levels and the amplifier exhibits interpulse interference for the repetition rates approaching 10 GHz.

In view of the above, it could be argued that document D5 teaches to have the interpulse separation sufficiently large so as to allow the inverted population levels to build up to a level determined by the biasing current and to thereby improve the optical

gain. A closer examination of Figure 7, however, shows that the intensity of the fourth pulse is greater than the intensities of the other pulses only over a small fraction (about 5 ps) of the pulse duration (about 50 ps) at the beginning of the pulse, and that for the remaining large duration, the fourth pulse has the same intensity as the other pulses. It therefore follows that the total energy of the fourth pulse is only marginally higher, and that the interpulse spacing does not noticeably affect the output power of the pulses. For these reasons, in the Board's view, the skilled person would not be led by document D5 to extend the time interval between the pulses.

Document D6 concerns a computer simulation of a semiconductor laser amplifier based on a theoretical model using a direct-current bias which is several times larger than the threshold current for lasing, so that it is doubtful whether the results plotted in Figure 1 showing gain as a function of pulse repetition rate would be applicable to an amplifier biased below the lasing threshold current as in the present invention (see page 6/1, second paragraph). Moreover, Figures 1 to 3 of the document show that beyond a pulse separation of about 3 ns, there is no increase in the gain. In other words, for a given input power, the peak output power remains the same when the pulse separation is increased beyond 3ns. As the typical recovery time is about 2ns (see the present application, page 3, line 19), it follows from document D6 that a pulse separation in excess of twice the recovery time would not lead to any increase in power output.

It follows from the present application (see page 2, line 26 to page 7, line 20) that it is well recognised in the art of semiconductor laser that optical power output of a laser is limited by the internal current density, as it is these carriers that produce output

power by electron-hole recombination. Also, since it is known in the art (see, e.g. document D1 or D5) that there is a finite recovery time for the carrier density to recover from the depletion level, a skilled person would expect the output power to increase with interpulse spacing up to the recovery time. Beyond that, however, he would not expect any improvement in the output power. Having regard to the above common general knowledge and the prior art discussed above, in the Board's view, an improvement in the output power for interpulse spacing in excess of twice the recovery time is surprising and would not be expected.

For the above reasons, in the Board's judgement, the subject matter of the independent claim 1 involves an inventive step within the meaning of Article 56 EPC.

## 2.2 Claim 4

The claim concerns an optical pulse source comprising a semiconductor laser amplifier and a drive means which are arranged or set up to operate as specified in the claim to generate output optical pulses having a peak power of at least 100mW. In particular, the drive means is set up to apply optical excitation pulses having a time interval in excess of twice the recovery time.

In Document D1, a semiconductor laser amplification assembly comprising a semiconductor laser amplifier (Si/Ge) and a drive means ( Kr/ Dye laser ) is described with reference to Figure 1 on page 1315, second paragraph. This assembly is not arranged or set up to produce a peak output power of at least 100mW. Similarly, the drive means is not set up to apply optical excitation pulses having a time interval in excess of twice the recovery time.

In document D2 a semiconductor laser amplification assembly is described on page 9, line 21 to page 19, line 31 with reference to Figure 4. The drive means does not supply a pulsed optical signal.

For the reasons set out above in connection with claim 1, it would not have been obvious to a skilled person to set up the semiconductor amplification assembly of document D1 or D2 to apply optical excitation pulses as set out in claim 4. In the Board's judgment, therefore, the subject-matter of claim 4 involves an inventive step within the meaning of Article 56 EPC.

Since the remaining claims are dependent claims, they also fulfil the requirement of inventive step.

## Order

For these reasons it is decided that:

1. The decision of the Examining Division is set aside.
2. The case is remitted to the first instance with an order to grant a patent on the documents specified in section IV above.

The Registrar:

The Chairman:

M. Beer

G. D. Paterson

