(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 May 2006 (11.05.2006)

PCT

(10) International Publication Number
WO 2006/048500 A1

(51) International Patent Classification:
B23K 26/03 (2006.01) *G01N 21/958* (2006.01)
B29C 65/82 (2006.01) *G06T 7/00* (2006.01)

(21) International Application Number:
PCT/FI2005/000469

(22) International Filing Date:
2 November 2005 (02.11.2005)

(25) Filing Language: Finnish

(26) Publication Language: English

(30) Priority Data:
20041414 3 November 2004 (03.11.2004) FI

(71) Applicants *(for all designated States except US)*: **VALTION TEKNILLINEN TUTKIMUSKESKUS** [FI/FI]; PL 17021, Laserkatu 6, FI-53851 Lappeenranta (FI). **EMMECON OY** [FI/FI]; PL 35, Hietakallionkatu 2, FI-53851 Lappeenranta (FI).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **JANSSON, Anssi** [FI/FI]; c/o VTT, PL 17021, FI-53851 Lappeenranta (FI).

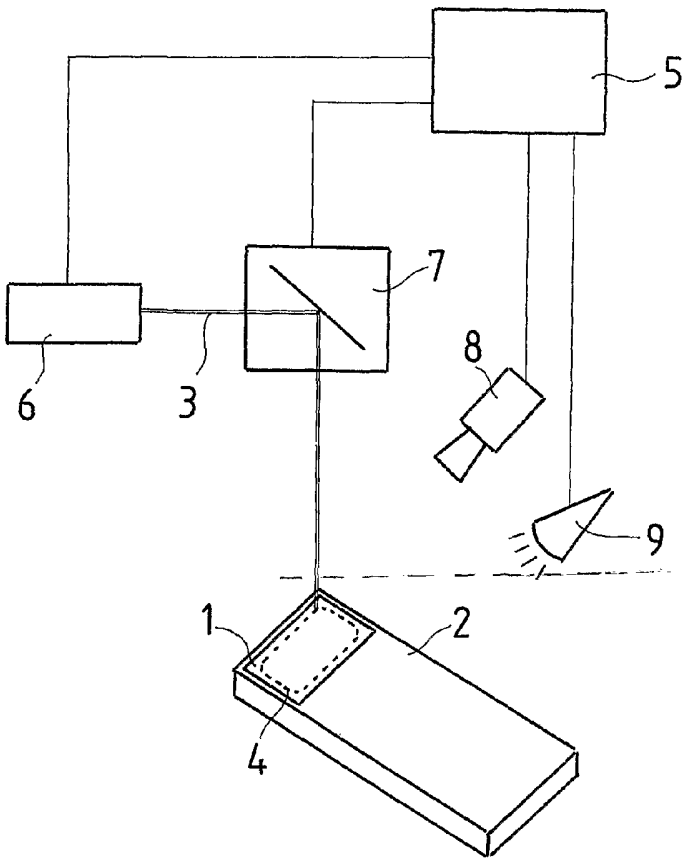
(74) Agent: **PAPULA OY**; P.O. Box 981, Mechelininkatu 1 A, FI-00101 Helsinki (FI).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: LASER WELDING METHOD



(57) Abstract: A laser welding method for welding together two plastic components, a first plastic component (1) i.e. one that is permeable to laser radiation and a second plastic component (2) i.e. one that is non-permeable to laser radiation, in which method a laser beam (3) is directed through the first component into the second component and the laser beam is moved along a predetermined path (4); the components are held substantially in engagement with one another at least in the area of welding and during the entire welding, resulting in that as the laser beam is absorbed in the second component, the latter starts to melt in the area of radiation, thereby melting the first component so that the molten areas of the components adhere to one another forming a seam, and the components are welded together; criteria for an acceptable seam are determined; and a product is accepted when the criteria for an acceptable seam are met . According to the invention, the laser beam is moved several times along a predetermined path; the melting of the components and the formation of the seam are monitored substantially continuously using image processing technology as the welding proceeds through the first plastic component; criteria for the image of an acceptable seam are determined, and the welding is stopped as the criteria are met.

WO 2006/048500 A1

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

LASER WELDING METHOD

FIELD OF THE INVENTION

The invention relates to a laser welding method as defined in the preamble of claim 1 for attaching together two plastic components that are different as their permeability to laser radiation is concerned, i.e. one permeable to radiation and one non-permeable to radiation.

BACKGROUND OF THE INVENTION

In welding together two plastic components, often a more massive component and a plastic film, by means of a laser beam, the welding is performed using rivet welding so that the laser beam permeates the topmost plastic transparent to the wavelength of the laser, but not the lower plastic non-transparent to the wavelength of the laser. In that case, the lower plastic absorbs the laser radiation directed to it so that it will heat and melt, thereby starting to melt the topmost transparent plastic that is in a suitable pressure contact therewith. When the plastics are molten in the area of the weld being produced and sufficiently mixed together, heating is stopped. After the weld has cooled, the plastic parts have been fixedly welded together.

The requirement of a successful weld is that the plastics that are to be welded together are in a close contact with one another in the entire area of the weld to be made, that is both along the length and the width during the entire welding process. Due to this, welding flaws are easily produced in case, irrespective of the compression together, the plastics are not sufficiently well attached to one another, for example, because of an air bubble, trash, a flaw in the material or some other fault.

This kind of welding uses mainly semi-simultaneous welding, in which the laser beam is deflected along a predetermined path by means of scanner mirrors, for example, under the control of a numerical path guide tens and even hundreds of times consecutively. When the cycle length of the path is sufficiently short, the welding path will heat more and more with each cycle until the surfaces of the parts to be attached together will melt; the molten parts will be mixed with one another and welded together along the entire path almost simultaneously.

The problem with the prior-art technology is the quality inspection. Usually it is not until the welds are completed that they are inspected and defective ones eliminated because the prior-art technology does not offer any possibilities to monitor how the weld is produced and to adjust the welding process when making the weld.

The problematic prior-art technology referred to above has been described, for example, in publication A1 Habaeih et al, " A novel approach for quality control system using sensor fusion of infrared and visual image processing for laser sealing of food containers", Measurement Science and Technology, 15 (2004), pp. 1995-2000, publish. 20/8/2004, ISSN 0957-0233. In this publication, it is not until a few seconds from the completion of the seam that it is monitored based on the heat radiation emitted from it, and the products with a defective seam are discarded.

OBJECTIVE OF THE INVENTION

The objective of the invention is to eliminate the aforementioned disadvantages of the prior-art. One specific objective of the present invention is to disclose a new kind of method that enables monitoring the formation of a seam in real time and adjusting the welding so that flaws in the seam can be

prevented, and when making the seam, flaws in the seam can be fixed as they appear prior to the completion of the seam.

SUMMARY OF THE INVENTION

The laser welding method of the invention is characterised by what has been described in claim 1.

The laser welding method of the invention is used for welding together two plastic components, a first plastic component i.e. one that is permeable to laser radiation and a second plastic component i.e. one that is non-permeable to laser radiation. In the method, a laser beam is directed through the first component into the second component; the laser beam is moved along a predetermined path and the components are held substantially in engagement with one another at least in the area of welding, that is to say in the area of the seam being produced, and during the entire welding. In that case, as the laser beam penetrates the first component and is absorbed on the surface of the second component, the latter starts to melt in the area of radiation, while at the same time melting the surface of the first component at a corresponding point so that the molten areas of the components are mixed and adhere to one another, and when the radiation is stopped and the components cool, the components have been welded together. When acceptability criteria have been imposed on the seam to be produced, the seam can be accepted as the criteria are met. According to the invention, the laser beam is moved along a predetermined path several times in a row, and the melting of the components and the formation of the seam are monitored substantially continuously through the first plastic component using image processing technology. When acceptability criteria have been imposed on the image of the seam to be obtained using image processing technology, the laser welding and

formation of the seam proceed until the criteria are met, whereby the welding is stopped.

In the method of the invention, the formation of the seam is monitored substantially continuously, i.e. either in a continuous and uninterrupted manner of monitoring or suitably periodically and at short, given intervals as the welding proceeds, and the image taken of the seam is compared to given criteria that determine the finished seam. Thus, one proceeds with the welding as long as the criteria are not met and stop the welding as the criteria are met. On the other hand, in case the criteria are exceeded, i.e. one has welded too much so that, for example, too long a seam has been produced, the product is discarded.

Depending on the dimensions and shape of the seam to be produced, as well as the entire component to be processed, the laser beam can be moved either in parallel along a given path or back and forth along a given path.

In a smooth and flawless jointing process, the weld is usually simultaneously formed to be of uniform quality and width along its entire length. Because, however, there is a possibility to existing impurities or other deviations at least in the area of the seam, in one embodiment of the invention, the intensity of the laser beam can be adjusted at the different points of the seam to be produced, in its longitudinal or lateral direction, to form a seam that meets the criteria.

Alternatively or simultaneously with the adjustment of the intensity of the laser beam also the effect time of the laser beam can be adjusted at the different points of the seam being produced to form a seam that meets the criteria. Further in addition to the ~~aforementioned~~ ones, ~~or alternatively~~ together with them, because one uses a laser beam that sweeps over the seam several times, the effect times of the

laser beam at the different points of the seam to be produced can be adjusted to form a seam that meets the criteria.

In a preferred embodiment of the invention, the seam is welded using semi-simultaneous welding in which the laser beam is moved very fast along a predetermined path several times in a row to achieve sufficient melting. One keeps circling the path or moving back and forth along it so fast that the warming of the plastic to be heated is substantially uniform and continuous and the seam being produced will not get cool while the laser beam is circling the path.

The method of the invention for monitoring a seam is a continuous online process in which, as far as the success of the welding process is concerned, the system is tuned to the monitoring of the important issues, such as the development of the width of the weld that can be seen in the image area in the form of a stripe, along the entire stretch of the weld; the uniformity of the stripe or some other typical quantity. If during the processing, it seems like the weld is not going to be uniform throughout, the process parameters can be changed adaptively so that uniformity is reached, or at least a uniform outcome is achieved. If changing the process parameters will not help and the final quality of the weld remains below the acceptability limit, then the system will provide this information for discarding the article in question.

Depending on the shape and dimensions of the seam, the application, the use requirements or the like, the criteria for an acceptable image of a seam can include the following facts: the width of the seam, the uniformity of the width along the entire length of the seam, the uniformity of the contours of the seam, the straightness of the seam contours, the uniformity and continuity of the seams and/or the uniformity of the colour of the surface of the seam area.

The image processing technology to be used in the method of the invention is not limited in any manner; instead various techniques known per se and obvious to a person skilled in the art can come into question. In that case, monitoring the criteria of the seam and the determination of the criteria can vary freely depending on the known image processing technology used. As one example we mention an embodiment in which the seam being produced has been divided into several small sections in respect to its surface area, and each of these sections is inspected separately. There are certain numbers of minimum and maximum pixels determined for each section, and in an acceptable seam, the number of pixels in the completed seam shall fall within these values. Other kinds of image processing techniques that monitor the process of producing an image of the seam and compare it to given values or reference images are also possible.

The method of the invention has several advantages compared to the prior-art technology. In welding together plastic components, the invention enables continuous monitoring and process control during the production. Thanks to this fact, the production process is accelerated, the number of faulty articles is almost eliminated and the need for inspecting the products after the process is eliminated. The products to be rejected can be identified and discarded from the process in an individual manner, resulting in that there is no need to wholly eliminate or demolish bigger production lots either, as it often is the case at present. Just the defective articles are eliminated. Hence, the invention has an important economic role in the laser welding industry of plastic components, particularly in huge mass production. As an example of applying the invention in practice we mention the welding of a transparent display screen to the casing of a mobile phone.

In the following section, the invention will be described with reference to the drawings, in which

Fig. 1 is a schematic view illustrating a system in which the method of the invention can be used; and

Fig. 2 represents a series of images illustrating the formation of a seam using the method of the invention.

As shown in Fig. 1, the system comprises a control unit 5 having a laser beam source 6 attached thereto, a guide system such as mirror equipment 7, for guiding the laser beam along a desired path, a camera 8 for taking an image of the seam being produced, as well as a light source 9 for illuminating the object being imaged. In the embodiment of the figure, as the plastic component 2 impermeable to a laser beam serves the casing of a mobile phone and as the plastic component 1 permeable to a laser beam a transparent display screen to be welded to the mobile phone casing.

The method functions as follows. Programmed in the control unit 5 is the path along which the laser beam is guided, using the mirror equipment 7, along the surface of the components 1 and 2 to be attached to one another. The control unit 5 is similarly informed of an acceptable seam, that is of those criteria which need to be met and which cannot be exceeded in order that the seam being produced can be accepted. After one has placed on top of the casing 2 the display screen 1 to be attached thereto, the latter is held suitably in place, for example, by pressing it by the very edges against the casing 2. Thereafter, the laser beam 3 is directed by means of the mirror equipment 7 to the casing 2 through the display screen 1 while the beam keeps constantly moving and circling a predetermined path 4. In that case, the energy of the beam is absorbed in the casing, resulting

in that the latter starts to heat and melt on the surface. This melting also melts the display screen 1 at the corresponding point, so that the molten areas of the components 1 and 2 are united, thereby forming a seam that welds the components together. The formation of the seam is continuously monitored using the camera 8 and by comparing, using a suitable image processing technique, the image of the seam being produced to the image of an acceptable seam included in the control unit 5. If necessary, the seam can be further illuminated with a lamp 9 using visible light of suitable colour or other radiation so that the image taken of the seam is better and sharper. When the image taken of the seam being produced matches, with sufficient accuracy, with an image of an acceptable seam, the welding is stopped.

In a normal situation, the laser beam keeps circling at a regular speed and with a regular power for a sufficient period of time, e.g. 0.5 to 2 seconds, after which one has obtained a smooth seam of uniform width along the entire length about the display screen. If, however, the components are not uniformly attached to one another; there is air or trash between them, etc., there can be points of non-uniformity in the seam. In that case, the laser beam is guided so that at a point of non-uniformity, the intensity of the laser beam is increased; it is moved more slowly over this place; or the laser beam is even guided back and forth just in this place for a while so that the seam will be of desired width and will meet the criteria defined for it also in the place in question. In case the seam cannot be made to meet the acceptability criteria in suitable time, or if as a result of the processing, the seam exceeds the criteria imposed on it in some respects, the component will be discarded, unless it cannot be accepted irrespective of the exceeding.

Fig. 2 represents a series of images illustrating the formation of a seam. The weld or seam being produced as shown in images a-h develops and gets wider at the same time with each sweep or scan of the laser beam. Finally, a sufficiently wide weld or seam that meets the given criteria is formed.

The area of a weld being produced as shown in image i can be divided into pixels, whereby the formation of the weld is monitored for each pixel specifically. Hence, when the weld occupies the area of sufficiently many pixels, the scanning can be stopped. To achieve the desired weld quality, the density of the pixels shall be selected to be sufficient.

Image j, in turn, shows how too high a laser intensity in relation to the scanning speed has done damage to the weld and produced bubbles in the middle of the weld. Here it is apparent that by keeping the individual pixels sufficiently small so that the size of the pixel corresponds to the size of the bubble, also these kind of defects in the weld can be noticed by examination of the pixels.

Image k shows a fault situation in which there is in the weld an air gap preventing a sufficiently wide and uniform welding. This kind of defect will be noticed even with a rather big pixel size.

The invention is not limited merely to the examples referred to above; instead many variations are possible within the scope of the inventive idea defined by the claims.

CLAIMS

1. A laser welding method for welding together two plastic components, a first plastic component (1) i.e. one that is permeable to laser radiation and a second plastic component (2) i.e. one that is non-permeable to laser radiation, in which method,

- a laser beam (3) is directed through the first component into the second component; and the laser beam is moved along a predetermined path (4),
- the components are held substantially in engagement with one another at least in the area of welding, and during the entire welding, whereby as the laser beam is absorbed in the second component, the latter starts to melt in the area of radiation, thus melting the first component so that the molten areas of the components adhere to one another, thereby forming a seam, and the components are welded together,
- criteria for an acceptable seam are determined; and
- the product is accepted as the criteria for an acceptable seam are met,

c h a r a c t e r i s e d in that

- the laser beam is moved several times along a predetermined path;
- the melting of the components and the formation of the seam are monitored substantially continuously using image processing technology as the welding proceeds through the first plastic component;
- criteria for an acceptable image of a seam are determined, and
- the welding is stopped as the criteria are met.

2. The method as defined in claim 1, characterised in that the laser beam is moved in parallel about a predetermined path.

3. The method as defined in claim 1, characterised in that the laser beam is moved back and forth along a predetermined path.

4. The method as defined in any one of claims 1-3, characterised in that the formation of the seam is monitored continuously and without stopping during the entire time the laser beam is focused.

5. The method as defined in any one of claims 1-3, characterised in that the formation of the seam is monitored periodically and at given intervals.

6. The method as defined in claim 1, characterised in that the intensity of the laser beam is adjusted at the different points of the seam to be produced to form a seam that meets the criteria.

7. The method as defined in claim 1, characterised in that the effect time of the laser beam is adjusted at the different points of the seam to be produced to form a seam that meets the criteria.

8. The method as defined in claim 1, characterised in that the effect times of the laser beam at the different points of the seam are adjusted to form a seam that meets the criteria.

9. The method as defined in any one of claims 1-8, characterised in that the seam is welded using semi-simultaneous welding in which the laser beam is guided along a predetermined path several times in a row to achieve a sufficient melting.

10. The method as defined in any one of claims 1-9, characterised in that the seam being produced is illuminated to improve the image taken of it.

11. The method as defined in any one of claims 1-10, c h a r a c t e r i s e d in that the criteria for the image of an acceptable seam include: the width of the seam, the uniformity of the seam, the uniformity of the contours of the seam, the straightness of the contours of the seam, the uniformity and continuity of the seam and/or the uniformity of the seam area.

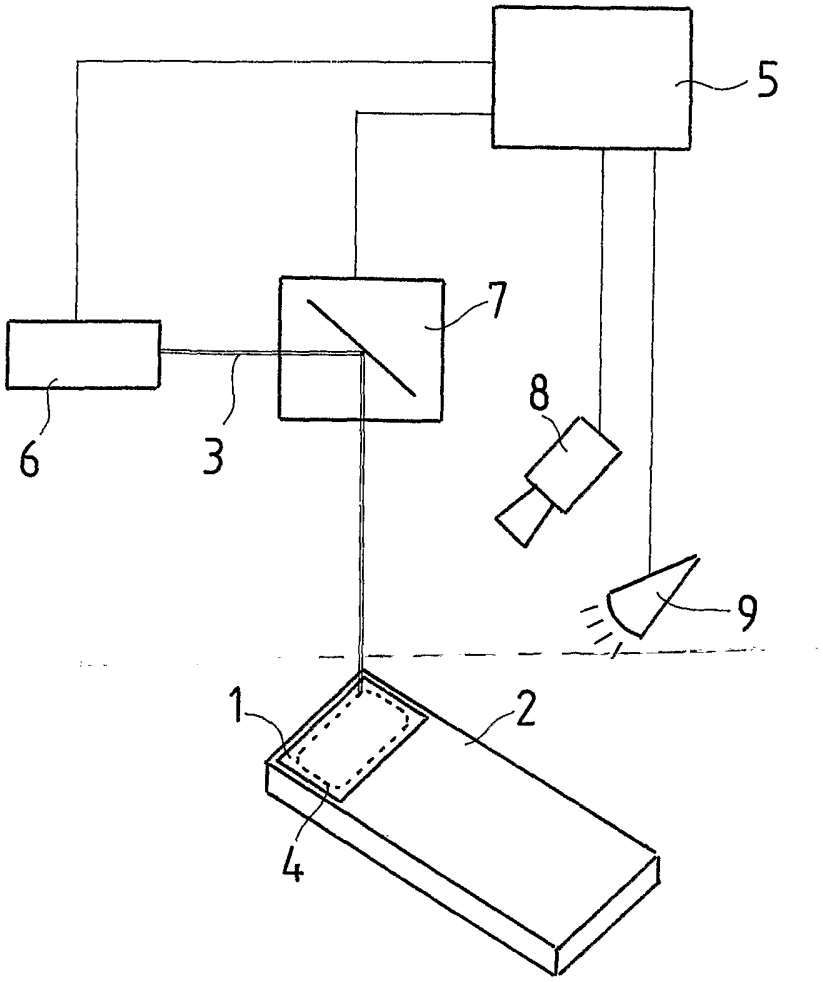


Fig 1

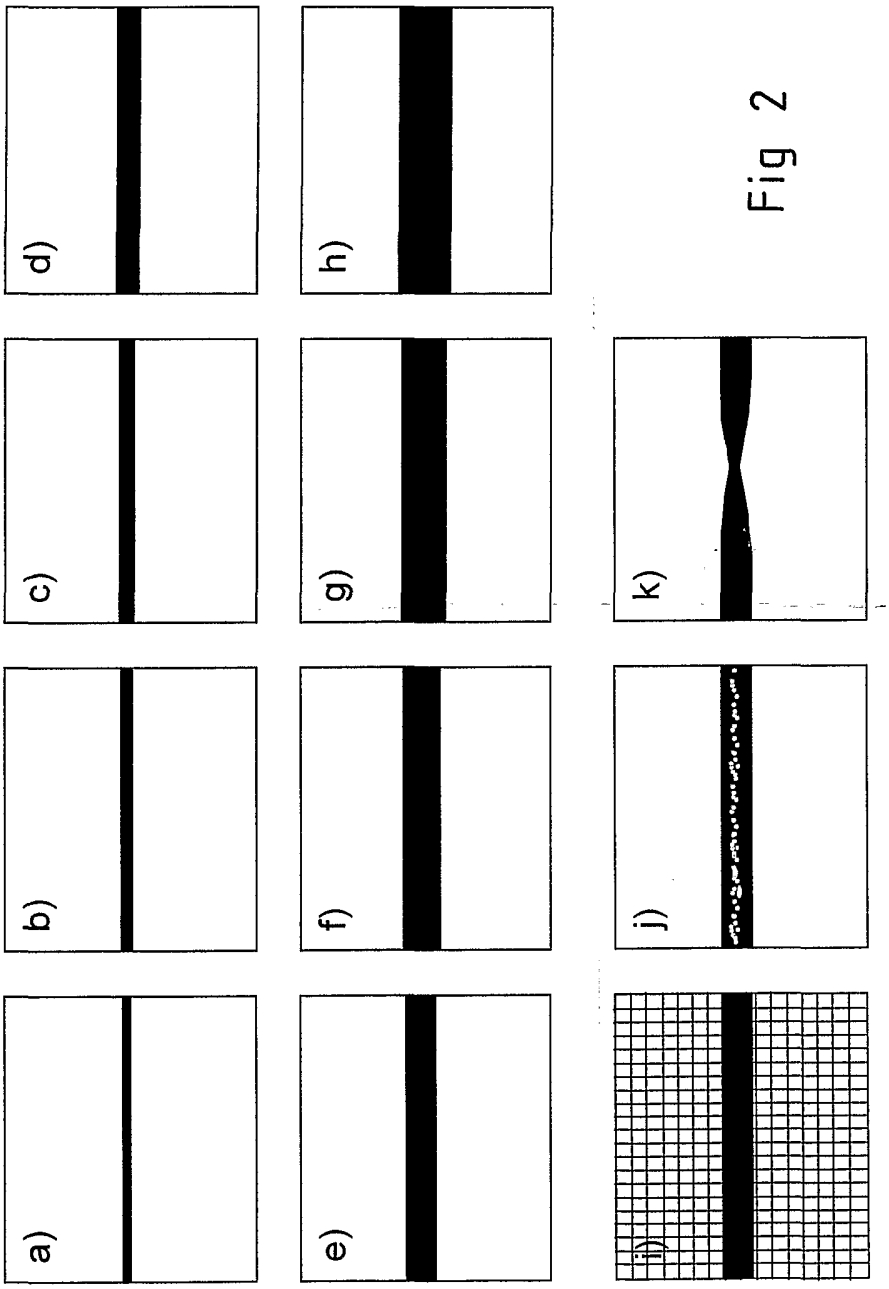


Fig 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI2005/000469

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC8: B23K, B29C, G01N, G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

FI, SE, NO, DK

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC,WPI,TXTE,TXTG,TXTF

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1304560 A1 (LASERQUIPMENT AG) 23 April 2003 (23.04.2003), paragraphs 11-13, 16, claims 1-4, 11	1-11
X	US 2004114662 A1 (MESSLER ANDREAS) 17 June 2004 (17.06.2004), abstract, paragraphs 3, 11, 24, 25 and 32-36	1-11
X	Al-Habaibeh, Shi, Brown, Kerr, Jackson, Parkin, "A novel approach for quality control system using sensor fusion of infrared and visual image processing for laser sealing of food containers", Measurement Science & Technology, 15 (10) 2004, pp. 1995-2000, publ. 20.8.2004, pp 1995-2000	1-11
Y	US 5659479 A (DULEY WALTER W et al.) 19 August 1997 (19.08.1997), abstract, column 1, lines 17-63, column 5, lines 45-67, column 6, lines 29-67, column 9, line 55- column 10, line 9, column 13, lines 39-48	1-11
Y	JP 2004167840 A (AISAN IND) 17 June 2004 (17.06.2004), abstract	1-11

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 January 2006 (23.01.2006)	03 February 2006 (03.02.2006)

Name and mailing address of the ISA/FI	Authorized officer
National Board of Patents and Registration of Finland P.O. Box 1160, FI-00101 HELSINKI, Finland	Rauli Erävalo
Facsimile No. +358 9 6939 5328	Telephone No. +358 9 6939 500

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/FI2005/000469

Patent document cited in search report	Publication date	Patent family members(s)	Publication date
EP 1304560 A1	23/04/2003	DE 10151345 A1	30/04/2003
US 2004114662 A1	17/06/2004	JP 2004525382T T	19/08/2004
		WO 02090953 A1	14/11/2002
		EP 1390727 A1	25/02/2004
		DE 10158095 A1	05/06/2003
		DE 10121923 A1	14/11/2002
US 5659479 A	19/08/1997	US 5517420 A	14/05/1996
		GB 2283113 A	26/04/1995
		EP 0724497 A1	07/08/1996
		WO 9511106 A1	27/04/1995
		CA 2174500 A1	27/04/1995
		AU 7935394 A	08/05/1995
JP 2004167840 A	17/06/2004	None	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI2005/000469

CLASSIFICATION OF SUBJECT MATTER

Int.Cl.
B23K 26/03 (2006.01)
B29C 65/82 (2006.01)
G01N 21/958 (2006.01)
G06T 7/00 (2006.01)