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(54) Laser-indured thermal dye transfer using reverse exposure.

(57) A method of thermal printing with a thermal printing dye-donor (10) having a light-to-heat converting material mixed with the thermal dye material (19) on a support member (14). The method comprises the steps of superposing a receiver member transparent to an information bearing radiation beam with the support member carrying the thermal dye material. An information-bearing radiation beam (22) is generated by supplying an information-bearing power signal to a radiation-generating device, and the thermal dye material is exposed to the information-bearing radiation beam through the receiver member (12) to transfer thermal dye material from the support member to the receiver member to generate an image on the receiver member, with the image having a density which varies linearly with the power level supplied to the radiation-generating device.

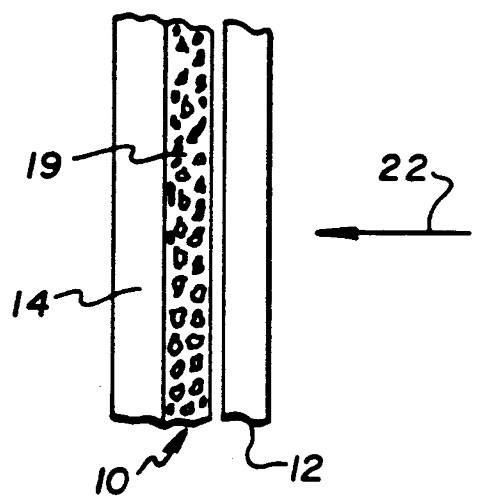

FIG. 3

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The present application is related to my co-pending applications, having Serial No 997,377, entitled DYE ROLLERS FOR LASER THERMAL DYE TRANSFER, and Serial No 996,999, entitled SOLID DYE ROLLERS FOR LASER THERMAL DYE TRANSFER, both filed on even date herewith.

Field of the Invention

The present invention is directed to the generation of prints from electronic data and, more particularly, to a novel thermal printing method and apparatus that employs reverse exposure of the dye-donor and receiver to obtain improved latitude in the printing process.

Background of the Invention

Thermal transfer systems have been used to generate prints from pictures which have been recorded from a color video camera or other electronic source, or which have been stored electronically from any source. Typically, the image is first separated into color separations, e.g. by passing the image through color filters and converting the respective color-separated images into electrical signals representing, for example, the cyan, magenta and yellow images. When the image is to be printed, these electrical signals are individually transmitted to a printer where each color is individually printed to generate a full color image. In one form of a thermal printer cyan, magenta and yellow dye-donor elements (sheets) are placed sequentially face-to-face with a dye-receiving element (sheet) and the mated dye-donor and receiver elements are inserted between a thermal printing head and a platen. The preferred method of thermal printing has heretofore employed the "forward" exposure process wherein the mated sheets are oriented so that the dye-donor sheet is adjacent the thermal printing head which applies heat to the back of the dye-donor sheet to drive the image dye in the forward direction, toward the receiver sheet. The thermal printing head has many heating elements which are sequentially actuated in response to the color signals. The process is then repeated for each of the other colors and a color hard copy is thus obtained which replicates the original image. One such process and apparatus is disclosed in U.S. Patent No. 4,621,271, which is hereby incorporated by reference.

Other processes of obtaining thermal prints from electronic signals substitute one or more lasers for the thermal printing head. In such systems, the dye-donor sheet includes a material which strongly absorbs at the wavelength of the laser. When the dye-donor is irradiated with the beam of coherent light from the laser, the absorbing material converts the light energy to thermal energy and transfers the heat to the dye in the immediate vicinity, thereby heating the dye to transfer it to the receiver. The absorbing material may be present in a layer beneath the dye and/or it may be admixed with the dye. The laser beam is modulated by the electronic signals which are representative of the shape and color of the original image, so that each dye is heated only in those areas in which its presence is required on the receiver to reconstruct the color of the original object. Further details of this process are found in British Patent No. 2,083,726A, the disclosure of which is also hereby incorporated by reference.

Published Japanese Patent Application No. 03/26595, published February 5, 1991, teaches a laser thermal process in which the exposure is through a transparent receiver sheet, i.e. in the reverse direction toward a dye-donor element in which the light absorbing, heat producing layer is disposed as a discrete layer behind the dye layer. This publication alleges that the method taught therein provides higher print density or faster writing speed. In addition, it states that its method results in less adhesion failure between the dye-donor coating and the light absorbing layer than when forward printing through a transparent dye-donor element.

While thermal printing processes employing both the forward and reverse exposure have been employed in systems employing a discreet layer of light-absorbing, heat-producing material beneath the dye layer, and employing forward exposure in systems employing a light-absorbing, heat-producing material admixed in the dye layer, these processes all share the problem that the final print density is highly susceptible to undesirable variability depending both upon the coating thickness uniformity of the dye layer and the optical density uniformity of the light-absorbing, heat-producing material. In other words, it has been found with all of the foregoing thermal systems, that variations in the coating thickness of the dye-donor dye layer will appear in the final image as undesirable variations in image density. Similarly, any variations in the optical density of the light-absorbing material also results in undesirable image density variations. With the necessity of maintaining very close tolerances in the manufacture of the dye-donor element to control both the optical density of the light absorbing material and the thickness of the dye layer, the cost of the dye-donor element is significantly increased, making the process more expensive and less commercially acceptable.

Still further, it has been found that, in prior art thermal processes employing thick dye layers, e.g., greater than approximately two microns thick, the relationship of power input to print density is non-continuous in that the change in print density resulting from a linear change in power input is not linear; the print density change can be disproportionate to the change in the power input. Such a non-linear density-to-power response makes it difficult, if not impossible, to obtain repeatable, satisfactory results.

Summary of the Invention

Accordingly, it has been found that it is possible to overcome the problems of the prior art to provide a thermal image which is insensitive to donor dye thickness variations, permitting less strict manufacturing tolerances and costs, resulting in a lower cost dye-donor material. At the same time, the present invention provides a thermal printing process and apparatus which assures the production of an image in which the density varies linearly with the power level supplied to the radiation-generating device without unwanted discontinuities or variations in the power-to-density relationship which adversely affect the quality of the image produced.

Thus, according to a first aspect of the present invention, a method is provided for thermal printing with a thermal printing dye-donor having a light-to-heat converting material mixed with the thermal dye material on a support member. The method comprises the steps of: superposing a receiver member transparent to an information bearing radiation beam with the support member carrying the thermal dye material. An information-bearing radiation beam is generated by supplying an information-bearing power signal to a radiation-generating device, and the thermal dye material is exposed to the information-bearing radiation beam through the receiver member to transfer thermal dye material from the support member to the receiver member to generate an image on the receiver member, with the image having a density which varies linearly with the power level supplied to the radiation-generating device.

According to one embodiment, the radiation beam has a wavelength in the infrared region and the receiver member is transparent to infrared radiation.

According to another embodiment, the radiation beam has a wavelength in the visible region and the receiver member is transparent to visible radiation.

According to another aspect of the present invention a thermal printer is provided for use with a thermal printing dye-donor having a light-to-heat converting material mixed with the thermal dye material on a support member. Means is provided for superposing a receiver member with the support member carrying the thermal dye material, with the receiver member being transparent to an information bearing radiation beam. A radiation-generation means is provided for generating an information-bearing radiation beam as a result of an information-bearing power signal which is supplied to the radiation-generating means. Means is provided for directing the information-bearing radiation beam through the receiver member to transfer the thermal dye material from the support member to the receiver member, with the image having a density which varies linearly with the power level supplied to the radiation-generating means and which is relatively insensitive to variations in the thickness of the thermal dye material on the support member.

Various means for practicing the invention and other features and advantages thereof will be apparent from the following detailed description of an illustrative, preferred embodiment of the invention, reference being made to the accompanying drawings.

Brief Description of the Drawings:

FIG. 1 is a cross-sectional view through a thermal print assemblage of the prior art having a receiver element and a dye-donor element having a discreet light-absorbing, heat-generating layer and illustrating both "forward" and "reverse" exposure;

FIG. 2 is a cross-section through a thermal print assembage of the prior art illustrating a dye-donor element having the light-absorbing, heat-generating material admixed in the dye layer for exposure in the "forward" direction; and

FIG. 3 is an illustration of a thermal print assemblage of the present invention wherein the light-absorbing, heat-generating material is admixed in the dye layer and the element is exposed in the "reverse" direction.

Description of the Preferred Embodiment:

FIG. 1 illustrates a pair of superposed thermal print elements comprising a dye-donor element 10 and a receiving element or sheet 12 disposed in spaced relationship thereto. The dye-donor element 10 comprises a support member or sheet 14, a layer of a light-absorbing, heat-generating material 16 and a dye layer 18. As taught by the prior art, these components are usually coated as a thin film onto a flexible transparent support. The receiver ordinarily consists of a thin polymer film coated on either an opaque or transparent support made of paper or a polymer sheet. A thin gap, having a thickness in the order of microns, is maintained between the dye-donor and receiver. The gap may be provided by spacers consisting of finely dispersed beads coated on the surface of the dye-donor or the receiver. Such an assembly may be exposed in the "forward" direction by an information-bearing radiation beam 20 which is produced by a light source such as a semiconductor laser which is driven by an information-bearing power signal in a manner well known in the art. The information-bearing radiation beam is directed through the support layer 14, which must be transparent to the radiation beam 20, where the beam is absorbed by the light-absorbing, heat-generating layer 16 and is turned into heat which is transferred to the dye layer 18 in that area, transfering dye to the surface of receiver sheet 12.

This thermal print assemblage may also be exposed with a "reverse" exposure wherein an information-bearing radiation beam 22 is directed through the receiver element 12, which in this instance must be transparent to the beam 22 and then passes through the dye layer 18, also transparent to the information-bearing beam 22, to interact with the light-absorbing, heat-generatimg layer 16 to generate heat to transfer the dye from the layer 18 back in the "reverse" direction, to the receiver sheet 12.

FIG. 2 illustrates another form of a prior art thermal print assemblage comprising dye-donor element 10 and receiving element 12 disposed in spaced relationship thereto. The dye-donor element 10 comprises a support member 14 and a dye layer 19 having the light-absorbing, heat-generating material admixed therein as taught in U.S. Pat. No. 5,126,760. According to the teachings of the prior art, such an assembly is exposed in the "forward" direction by an information-bearing radiation beam 20 which passes through the support payer 14 into the dye layer 19 wherein it is absorbed by the incorporated light-absorbing, heat-generating material to transfer dye in that layer to the receiver sheet 12. No "reverse" exposure of this type of prior art thermal print media has been known before the present invention.

According to the present invention, various advantages result from the discovery that a thermal print medium having an incorporated light-absorbing, heat-generating material admixed in the dye layer can be advantageously exposed in the 'reverse' direction. Such a process is illustrated in FIG. 3, wherein the dye-donor material 10, having a support 19 and dye layer 19 having admixed therewith the light-absorbing, heat-generating material, is exposed by an information-bearing radiation beam 22 entering through the transparent receiver 12 to transfer dye from layer 19 back in the "reverse" direction to form an image on the facing surface of the receiver element 12.

Experiments comparing forward and reverse exposure were conducted to illustrate the advantages and disadvantages of each printing method. Fundamental differences were found when a series of dye-donor layer thicknesses were investigated. Transparent receivers were prepared by coating approximately 1μm thick butvar on 7 mil Poly(ethylene terephthalate) support. A reference dye-donor was prepared on a 4 mil Poly(ethylene terephthalate) support by coating 1.29 g/M^2 of a mixture of cyan colored image dyes, 0.075 g/M^2 of a cellulosic binder, and 0.65 mg/M^2 of an IR absorbing dye, from a melt solution in dichloro-methane. The resulting dried dye-donor coating was about 1μm thick. A progression of layer thicknesses was prepared from melts, identical to the reference melt, having dry coverages, 0.25, 0.5, 1.0, 2.0, 4.0 and 5.0 times the reference coating thickness. Sensitometric data were obtained from step tablets and were printed on receivers using an 830nm diode laser focused to a spot approximately 14μm in diameter. Prints were scanned at 70 cm/s , with 10μm spacing between scan lines, and the laser power was varied in 16 equal increments from 0 to 37 mW. The printed receivers were fused in acetone vapor at room temperature for 7 minutes. Status A red transmission densities were read from the printed receivers using a calibrated X-Rite 310 Photographic Densitometer. The results are summarized in Table 1.

Table 1

Comparison Between Forward and Reverse Exposure for Donors of Widely Varying Coating Thicknesses.

Exposure Direction:		Forward			Reverse		
Coating No.	Thickness[a] (normalized)	D_{max}[b]	Speed[c] (W_{-1})	Contrast (o.d./mW)	D_{max}[b]	Speed[c] (W^{-1})	Contrast[d] (o.d./mW)
1	0.25	0.94	46	0.04	0.88	48	0.04
2	0.50	2.15	63	0.09	1.48	63	0.06
3	1.00	3.48	56	0.16	2.40	77	0.09
4	2.00	3.94	40	0.66	2.61	77	0.10
5	4.00	0.00	0	0.0	2.46	77	0.10
6	5.00	0.00	0	0.0	2.69	77	0.10

(a) Coating coverage normalized to a reference thickness (see text).

(b) Status A Red Transmission Density.

(c) Speed = (Laser Power Required to Achieve 0.3 o.d.)$^{-1}$.

(d) Slope of Status A Red Density v.s. power, determined at 1/2 D_{max} Density.

In Table I, D_{max} is the Status A red transmission density obtained from a patch written at maximum power (37 mW, 1.5×10^{-6} cm^2 spot, 70 cm/s scan rate). Speed is defined as the inverse of the power required to achieve 0.3 density. Contrast is defined as the slope of density vs. laser power, determined at 1/2 D_{max} density. The reference thickness ,t_{ref}, was chosen to give the best compromise between D_{max}, speed and contrast, with forward exposure, and corresponds to a coverage close to the upper limit for image dye as taught in the prior art. Given forward exposure, D_{max} density increased with dye-donor thickness up to twice the reference thickness, tref; however, at or above twice tref, dye density falls off sharply at lower laser powers. This is indicated by the decrease in speed and the increase in contrast. At four times t_{ref} no dye transfer occurred at any laser power up to 37 mW. These trends translate into problems maintaining print uniformity, tone scale and sensitivity in the presence of coating thickness variations.

Reverse exposure also showed increasing D_{max} density with increasing dye-donor thickness up to a point; however, D_{max} did not fall off at higher coverages, but approached a limiting value. The speed and contrast also increased over this range, approaching limiting values. The contrast remained low over the entire thickness range, relative to forward exposure. Furthermore, the dependence of dye transfer density on laser power remained essentially linear at all coverages. Therefore, a print engine based on reverse exposure of a dye-donor having the light-absorbing, heat-generating material mixed with the image dye is more robust and less sensitive to coating variations in dye-donor thickness when the dye layer is thick. It is recognized that the optimum thickness for forward exposure depends upon the available laser power and spot size. It is further noted that, for thick dye-donors and limited laser powers, reverse exposure exhibits higher speeds and D_{max}.

It has also been discovered that using reverse exposure and thick dye-donor layers makes possible the use of multi-pass printing from a single dye-donor. Multi-pass dye-donors present several advantages over single use dye-donors such as less wasted material, and less time wasted in changing the dye-donors. It also allows a flexibility in design such as the use of dye-donor rollers or other opaque substrates. Dye donors, according to the present invention, were printed successively onto transparent receivers in the forward and reverse direction. For forward exposure the receiver was placed on the platen and dye-donor placed, dye-side down, on top. After the first print exposure, the two films were removed and a new receiver placed on the platen. The used dye-donor was re-registered manually to print over the exposed area. For reverse exposure, a dye-donor sheet was placed, dye-side up, on the printer platen. Receivers were placed over the dye-donor and printed, one after another, until the dye transfer density dropped substantially. Printed receivers were fused in acetone vapor at room temperature for 7 minutes, and Status A red transmission densities were read using a calibrated X-rite 310 Photographic Densitometer. The results are summarized in Table 2.

Table 2

Comparison Between Forward and Reverse Exposure for Multiple Printings from a Single Donor

Coating	Thickness	Pass	Forward D_{Max}	Reverse D_{Max}
3	1x	1	3.91	2.17
		2	1.10	0.84
6	5x	1	0.0	2.62
		2	0.0	2.48
		3	0.0	2.39
		4	0.0	2.41
		5	0.0	2.41
		6	0.0	2.30
		7	0.0	2.00
		8	0.0	1.42

As before, the reference dye-donor with a thickness of (1x) was exposed in the forward direction and gave a higher D_{max}. Attempts to print from the same dye-donor more than once however, resulted in excessive loss of dye density and unwanted patterns in the second image from the previous exposure. Reverse exposures of the reference coating produced similarly less than satisfactory results. At five times the reference thickness (1x) forward exposure produced no dye transfer at all, whereas a reverse exposure resulted in a density of 2.6 at D_{max}. Successive transfers from the same dye-donor resulted in little loss of D_{max}, which was still above 2.4 after 5 passes. Excessive loss occured only after the dye layer was exhausted, in this case after about 7 or 8 passes. At higher dye coverages more passes could be printed from a single dye-donor.

Thus, with the present invention, printing can be a continuous process. For example, a four station printer can simultaneously print full color records of the images. Given a continuous stream of images, time per print can be that of one station.

Thus, it will be seen that with the present invention, reversed exposure thermal printing provides a process which is less sensitive to dye coating thickness variations and to limits on the thickness of the dye layer. Moreover, the relationship of the image density produced to the laser power (above a power threshold) remains linear over a broader range of conditions. The printing apparatus of the present invention can utilize a thick dye donor in many forms and laser-induced dye transfer via an exposure through a transparent receiver. In fact there is essentially no limit to the thickness of the dye donor layer with reverse exposure. Also, transferred-dye-density is less sensitive to variations in the thickness of the dye-donor. With the use of thick dye-donor layers, reverse exposure can result in higher sensitivity, which is analogous to higher photographic speed, lower contrast, which in turn results in less image contouring, and better print uniformity. Since the dye layer can be essentially infinitely thick when exposing through the receiver, dye rollers, drums or solid dye rollers, can be used in place of coated dye-donor films, as noted in the above-mentioned copending patent applications.

The invention has been described in detail with particular reference to a presently preferred embodiment, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

Claims

1. A method of thermal printing with a thermal printing dye-donor having a light-to-heat converting material mixed with the thermal dye material on a support member, the method comprising the steps of:
superposing a receiver member transparent to an information bearing radiation beam with said support member carrying said thermal dye material,
generating an information-bearing radiation beam by supplying an information-bearing power signal to a radiation-generating device, and
exposing said thermal dye material through said receiver member to said information-bearing radiation beam to transfer thermal dye material from said support member to said receiver member to generate an image on said receiver member, which image has a density that varies linearly with the power level above a power threshold supplied to said radiation-generating device.

2. The method of thermal printing according to claim 1 wherein the image generated is insensitive to variations in the thickness of said thermal dye material on said support member.

3. The method of thermal printing according to claim 1 wherein said thermal dye material on said support member has a thickness substantially greater than about 2 microns.

4. The method of thermal printing according to claim 1 wherein said radiation beam has a wavelength in the infrared region and said receiver member is transparent to infrared radiation.

5. The method of thermal printing according to claim 1 wherein said radiation beam has a wavelength in the visible region and said receiver member is transparent to visible radiation.

6. A method of thermal printing with a thermal printing dye-donor having a light-to-heat converting material mixed with the thermal dye material on a support member, the method comprising the steps of:
superposing a receiver member transparent to an information bearing radiation beam with said support member carrying said thermal dye material,
generating an information-bearing radiation beam by supplying an information-bearing power signal to a radiation-generating device, and
exposing said thermal dye material through said receiver member to said information-bearing radiation beam to transfer thermal dye material from said support member to said receiver member to generate an image on said receiver member, which image has a density that varies linearly with the power level above a minimum power threshold supplied to said radiation-generating device and which is relatively insensitive to variations in the thickness of the thermal dye material on said support member.

7. A method of thermal printing with a thermal printing dye-donor having a light-to-heat converting material mixed with the thermal dye material on a support member, the method comprising the steps of:
superposing a receiver member transparent to an information bearing radiation beam with said support member carrying said thermal dye material,
generating an information-bearing radiation beam by supplying an information-bearing power signal to a radiation-generating device,
exposing said thermal dye material through said receiver member to said information-bearing radiation beam to transfer thermal dye material from said support member to said receiver member to generate a first image on said receiver member, which image has a density that varies linearly with the power level above a power threshold supplied to said radiation-generating device, and
repeating the foregoing steps with the same dye-donor to generate a second image.

8. The method of thermal printing according to claim 7 wherein said second image is identical to said first image.

9. The method of thermal printing according to claim 8 wherein said second image is generated in superposed relationship with said first image to increase image density.

10. The method of thermal printing according to claim 7 wherein said second image is different from said first image.

11. The method of thermal printing according to claim 10 wherein said second image is generated on a sec-

ond receiver sheet.

12. A thermal printer for use with a thermal printing dye-donor having a light-to-heat converting material mixed with the thermal dye material on a support member, means for superposing a receiver member with said support member carrying said thermal dye material, said receiver member being transparent to an information bearing radiation beam

a radiation-generating means for generating an information-bearing radiation beam, means for supplying an information-bearing power signal to said radiation-generating means,

means for directing said information-bearing radiation beam through said receiver member to transfer said thermal dye material from said support member to said receiver member to generate an image on said receiver member, said image having a density which varies linearly with the power level above a power threshold supplied to said radiation-generating means.

13. A thermal printer for use with a thermal printing dye-donor having a light-to-heat converting material mixed with the thermal dye material on a support member, means for superposing a receiver member with said support member carrying said thermal dye material, said receiver member being transparent to an information bearing radiation beam

a radiation-generation means for generating an information-bearing radiation beam, means for supplying an information-bearing power signal to said radiation-generating means, and

means for directing said information-bearing radiation beam through said receiver member to transfer said thermal dye material from said support member to said receiver member to generate an image on said receiver member, said image having a density which varies linearly with the power level above a minimum power threshold supplied to said radiation-generating means and which is relatively insensitive to variations in the thickness of the thermal dye material on said support member.

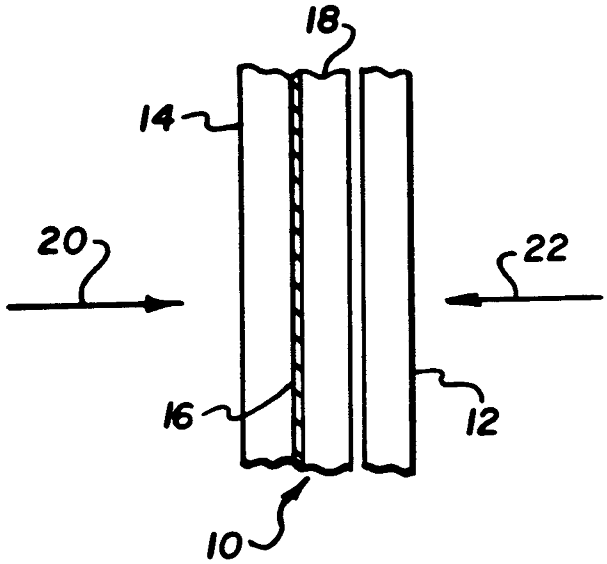

FIG. 1
(PRIOR ART)

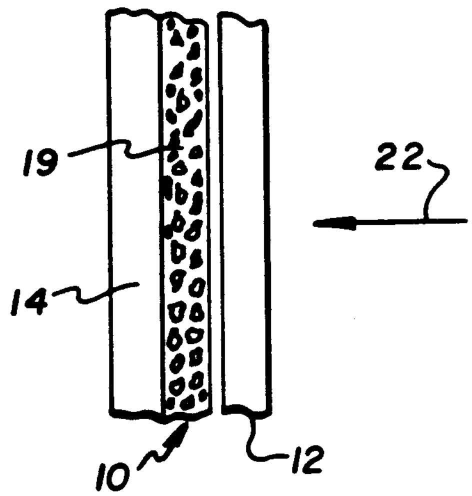

FIG. 3

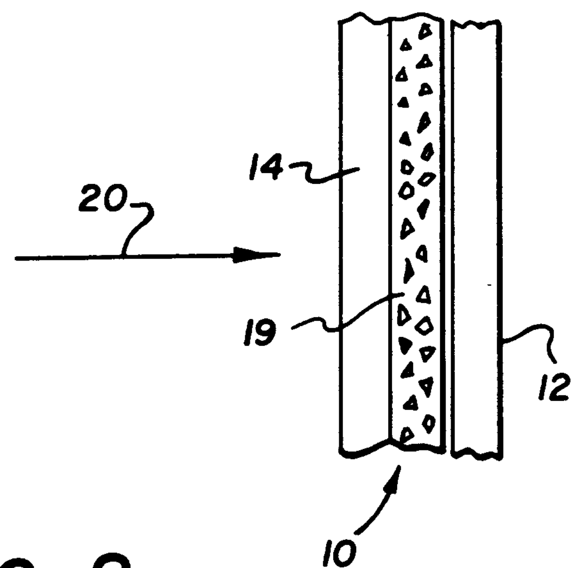

FIG. 2
(PRIOR ART)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 42 0507

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	PATENT ABSTRACTS OF JAPAN vol. 9, no. 264 (M-423)(1987) 22 October 1985 & JP-A-60 110 497 (MITSUI TOATSU KAGAKU K.K.) 15 June 1985 * abstract *	1-13	B41M5/38 B41M5/40 B41J2/475
X	EP-A-0 327 314 (R.J.REYNOLDS TOBACCO COMPANY) * figure 2 * * column 3, line 31 - line 43 *	1-13	
A	EP-A-0 318 946 (EASTMAN KODAK COMPANY) * page 2, line 46 - line 53 *	9	
A	US-A-4 804 975 (Y.KWOK-LEUNG) * column 1, line 48 - line 68 *	1-13	
A	EP-A-0 464 588 (EASTMAN KODAK COMPANY) * page 2, line 33 - line 58 *	1-13	

TECHNICAL FIELDS SEARCHED (Int.Cl.5)

B41M
B41J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22 April 1994	Markham, R

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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