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Use, Characterization, and Measurement of the Gloss Effects from Pigmented Ink Jet Inks for Security Printing

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Abstract. *The aim of this paper is to illustrate the use of gloss effects for security printing. These gloss effects can be produced using pigmented ink jet inks. The main reason for using this type of artifact for security printing is that the effects can be made invisible to typical desktop scanners while still remaining readable by the human eye and machine reading systems. The two gloss effects investigated are differential gloss and gloss color. In both cases, methods of visualizing and measuring these are considered with examples. The paper continues by giving examples of some of the variables that can be used to make this a secure system and concludes with a series of photomicrographs examining the root cause of these effects. © 2006 Society for Imaging Science and Technology.* [DOI: 10.2352/J.ImagingSci.Technol.(2006)50:6(537)]

INTRODUCTION

Ink jet printing technology continues to advance. One of the drivers for this has been the customer need for increased resistance to fading and physical durability. While these needs have in many respects been met by the use of pigmented inks this has resulted in the appearance of other issues. Depending on the application an end user may view these as positive and, hence, an attribute or negative and consider them a defect.

This paper deals with the gloss effects of differential gloss and gloss color. For photoapplications these can be considered as a defect as they make a print look different to the customer expectation, set by traditional silver halide based technology. However, these gloss effects can be used for security printing and in this application can be considered as an artifact.

GLOSS EFFECTS IN SECURITY PRINTING

The need for printing methods to counteract counterfeiting has a long history. New techniques are established but then circumvented by forgers. As a result, there will always be a call for new printing techniques to deter forgery and readily identify illicit copies to both machine readable and visual inspection.

The market opportunity on both sides is immense. In 2003, it was estimated that American industries lose around $250 billion a year to counterfeiting.[1] It is also estimated that counterfeit products make up as much as 9% of world trade. In addition, there is a national security dimension in that strong links are seen between counterfeit trading and international terrorism.[2]

Counterfeiting was once a skilled task. However, with the ready availability of high quality document scanners, personal computers, and desktop printers it is now comparatively easy to copy various printing techniques previously considered relatively secure. For example, scanning and ink jet printing have been shown to be a major method for currency forgery.[3]

One way to defeat desktop copying is to embed some machine or visually readable information into the gloss of the print. This information is then readable by viewing the gloss information as a specular reflection and as an image separate and distinct from that viewed by diffuse reflection. However, a conventional copier or scanner cannot see this specular information. Indeed, these devices are designed to avoid specular reflected light by illuminating at an oblique angle and detecting normally to the print. This is because the specular component normally contains little information of interest and reduces color saturation.

There are a number of examples of the use of gloss effects for security applications. One high profile example is the new $20 US banknote, designed to stay one step ahead of counterfeiters. Introduced in May 2003, among other security features it contains a “20” that is printed in ink that has a color that varies with the gloss viewing angle.

Also of interest here is the Xerox Glossmark™ technology.[4] Glossmark technology uses a toner or ink that has a gloss different to the substrate and will work best where these differences are pronounced. It works by modifying the halftoning structure in a directional fashion and is most applicable to midtones where the halftone structure reveals significant printed and unprinted areas.

Ink jet printing technology can also be used in a similar way for security applications.[5] The use of gloss effects in this context relies on the fact that ink jet inks can be formulated to give identical colors but different gloss levels. This means that if a print is made using a combination of these inks information can be printed that is readable only in the form of gloss information. It is therefore invisible to the copier and scanner systems mentioned above. This technique can be used to produce gloss effects for security without the directional nature of the half toning structures used for the Glossmark system. It can also be incorporated into more

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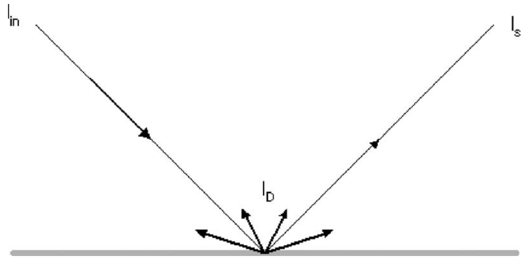

Figure 1. Reflection from a glossy print.

complex printed documents as one element in a "layered" deterrent to copying.[6]

Finally, ink jet inks can be formulated to give different gloss colors. Examples of these artifacts and the way in which they can be used for security printing will be illustrated in this paper.

Gloss effects also lend themselves to machine readability as the equipment can be as simple, cheap and compact as gloss meters.[7] Gloss level measurements also tend to be angle sensitive, adding to the security possibilities.

There is one further attribute that is pertinent to machine readability. This is the fact that such inks can be made to exhibit colored gloss effects as described below.

And finally, there is one last twist to this opportunity. As described above, most printing systems likely to be used by forgers produce some differential gloss effects. This can be removed by lamination but use of a sealable layer incorporated at media manufacture can allow for further gloss security effects to be introduced.[8]

CLASSIFYING GLOSS EFFECTS

There are two types of gloss effects dealt with in this paper. The first pertains to the magnitude of gloss achieved by the printed areas and the second with the color of that gloss.

The reflection from the surface of an ideal glossy print can be considered with reference to Fig. 1.

The incoming light I_{in} will be split into a specular reflected component I_S and a diffuse component I_D. The diffuse component is subject to the absorption by the colorants in the print. However, the specular reflection component I_S closely retains the spectral properties of the illuminant I_{in}. With white light incident the specular reflection will in turn look white. In more general terms, I_S will have a similar hue angle and shade to I_{in}.

In reality an observer viewing the specular component along I_S will view light over a finite cone angle and will therefore collect a portion of the (colored) diffuse light in addition to the white specular component. The result is that the gloss as viewed by an observer will always have a slight hue from the colorant.

A number of practical printing technologies exhibit the phenomenon known as differential gloss.[9,10] This is a change in gloss level as a function of printed density. A viewer can see this as a difference in gloss level as a function of both printed density and color.

In a number of practical situations gloss color is associated with differential gloss. Gloss color is the effect that is observed when the specular reflection I_S is a different color to the incident light I_{in}. Images printed with some pigmented inks show this effect. Images printed in black ink can look black by diffuse reflection but silver, gold, or green by specular reflection. This phenomenon is sometimes known as "bronzing."

Gloss color should not be confused with metamerism. Metamerism occurs when two samples match under one type of illuminant but do not match under another. It is a known issue with pigmented inks.[11] Gloss color is a different phenomenon to metamerism but it is easy to see why these two effects become confused. While metamerism is a change in color with different illuminant type, gloss color is a change in color with different illuminant gloss angle.

Gloss effects can be attributes, artifacts or defects, depending on the application. While a uniform high gloss is necessary to give a photorealistic look, differential gloss effects can find a use in security printing.[12]

EXPERIMENTAL DETAILS

All the examples used in this work were printed using commercially available glossy microporous ink jet papers and pigment inks. The initial gloss of these papers can be seen in the charts later in this paper. These ink media combinations were chosen simply to illustrate the variables that can influence gloss effects.

DIFFERENTIAL GLOSS

As described above, this is the difference in gloss level as a function of printed density. It is a well-known phenomenon most often noted at the high ink levels associated with ink jet[10] and electrophotographic prints.[13] Indeed printed matter often displays different reflective and diffusive characteristics depending on the orientation of the incoming light.[4]

As expected, the easiest way to measure this is with a gloss meter. The experiments described here used a Dr Lange Refo 3 gloss meter measuring to DIN 67530/ISO 2813. This measures visually weighted gloss to Illuminant C (representing indirect sunlight). ISO 2813 reference standard A, a sheet of black glass was used to set 100% gloss. As a result some of the figures cited below have gloss levels above 100%. For example, on this scale the gloss level of a completely reflective plane mirror would be around 380%.[14]

DIN 67530/ISO 2813 allows for measurements of gloss to be made at three angles of incidence. Initial measurements were made at all these angles of incidence (20°, 60°, and 85°). It was soon found that only the 20° and 60° measurements were of interest as the 85° results showed little if any correlation with visual perception. This correlates with accepted practice from ISO 2813 and follows the methodology of other work,[15] illustrated in Table I.

The gloss test patterns consisting of CMYKRGB stripes printed with ink coverage in steps of 0%, 5%, 10%, 20%, 30%…, 100% in line with this published work.[15]

We can define differential gloss in a numerical fashion. This report uses the numerical definition of differential gloss (G_{diff}) described in the external literature[16] and given in Eq. (1),

Table I. Gloss measurement angles.

20°	Best for differentiating high gloss samples (over 70%).
60°	General-purpose measurements (30%–70%).
85°	Low gloss levels such as matt papers.

Table II. Defining the sign of differential gloss.

dG/dL is positive over this range of *L*. In other words, gloss rises with ink density.	In this case we refer to the ink as having positive differential gloss[a].
dG/dL is negative over this range of *L*. In other words, gloss falls with ink density.	In this case we refer to the ink as having negative differential gloss.
dG/dL becomes both positive and negative over this range of *L*.	In this case we refer to the ink as having complex differential gloss.

[a]See Ref. 17.

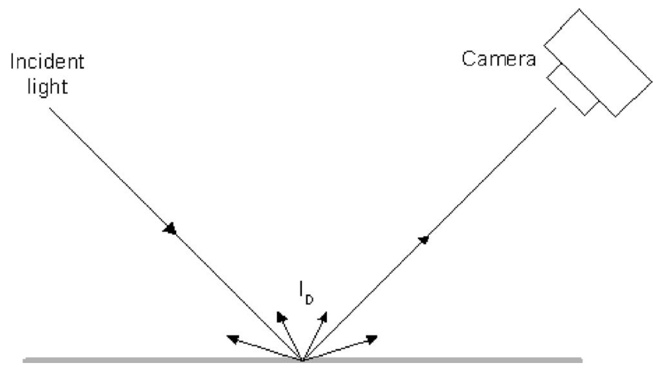

Figure 2. Visualizing gloss effects.

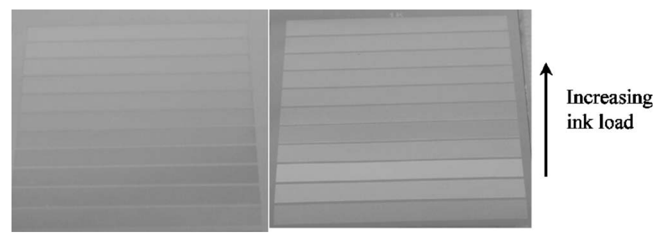

Figure 3. Pictures of the gloss of black ink step wedges.

$$\text{Differential gloss:} \quad G_{\text{Diff}} = G_{\text{max}} - G_{\text{min}}, \tag{1}$$

where G_{max} and G_{min} are the maximum and minimum gloss values obtained from a range of ink levels from 0% to 100%.

In some cases G_{diff} is a straightforward function of ink level L for a given media. However, in some cases G_{diff} is a complex function of L, rising and falling over the range of L under consideration. For the purpose of this work we can define the signs of the differential gloss as described in Table II.

As a general case, pigmented ink jet inks printed on porous media exhibit positive G_{diff} and dye based inks printed on swellable polymer media exhibit negative G_{diff}. Some real examples of positive and complex differential gloss are shown later in this paper (Fig. 7).

More complex definitions pertaining to differential gloss of printed color have appeared in the patent literature[18,19] but this simple definition was found to be appropriate in this work. In order to fully investigate the use of gloss effects for security printing some method of reproducibly visualizing these was required.

Following from published work,[20,21] a simple, pragmatic solution was used, as illustrated in Fig. 2. An extended light source (an outside window) was used, as this would be a typical "real world" illumination condition. By judicious positioning of the sample various angles of incidence can be selected. The gloss image was acquired using a commercial digital camera, in this case a Canon Powershot A40. Pictures of two step wedges printed with different pigmented black ink are illustrated in Fig. 3, taken at an angle of incidence close to 60°. For the purpose of this illustration, this image was recorded in monochrome—see below.

The left hand image in Fig. 3 shows an example of slight positive differential gloss, the right hand image an example of complex differential gloss. It also illustrates that the very different gloss behaviors of these two black inks can be adequately visualized using the simple apparatus illustrated in Fig. 2.

Figure 3 also shows that differential gloss effects can be made machine readable using simple apparatus. This offers the prospect that such effects could be made into overt or covert security features that are machine readable.

It has been shown in the previous section that one of the virtues of gloss effects for security printing is that it can be utilized in both machine and human readable form. Because of this we should also consider the subjective impression of differential gloss in order to assess the visibility to a human eye.

Published work using rank order psychophysics experiments has shown that the just noticeable difference (JND) of differential gloss for glossy paper substrates is around 20% of unprinted gloss. In addition it was shown that a differential gloss greater than 30 units is not desirable for photoapplications.[16] This is because it produces an impression of an uneven finish and a perceived three-dimensional surface relief that is deemed very objectionable. However, this does mean that for security applications a differential gloss of such a magnitude would be highly visible.

Additional work[17] on gloss test targets suggests that for uniform black areas the JND is 14%. It was also found[22] that gloss discrepancy within the image plays a major role in visual preference. The eye picks on the difference between the predominant gloss in the image and the other areas. If the image contains a significant fraction of unprinted areas,

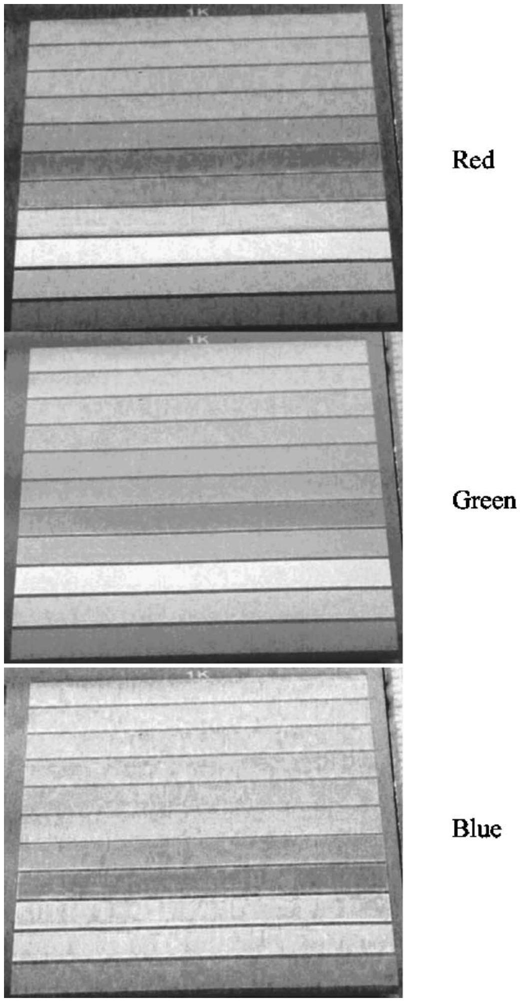

Figure 4. Black ink step wedge gloss imaged in R, G, B.

such as text on a plain background or a white border it is the gloss difference between printed and unprinted areas that matters. This has obvious implications for the visibility for gloss artifacts for security applications. It has also been shown[23] that differential gloss reduces the perceived gloss of an image. As a result, ink media combinations showing high differential gloss may be perceived visually as having a lower overall gloss than less glossy but more gloss-uniform images.

GLOSS COLOR

As discussed earlier this is the effect that is observed when the surface specular reflection is a different color to the incident light. In ideal glossy photoprint will have a spectral content of I_S that closely follows that of I_{in} (Fig. 1). However, in some cases the spectral content of I_S is very different to both I_{in} and I_D. In this circumstance we can state that the sample exhibits gloss color.

The apparatus illustrated in Fig. 2 is also very effective in recording gloss color. This work used a consumer color digital camera, and samples that produce gloss color can therefore be imaged directly with this apparatus.

The right hand image in Fig. 3 generates gloss color at certain illumination angles. This effect can also be used for

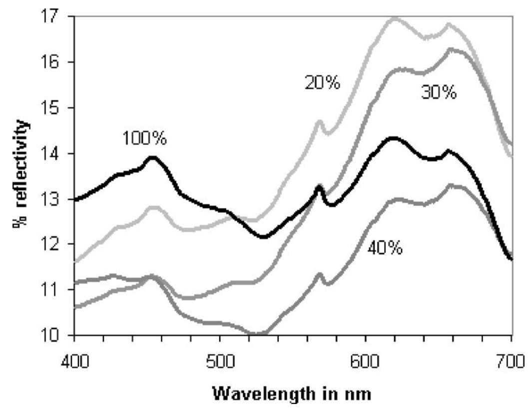

Figure 5. Specular reflectance spectra at 60°.

machine readability, as illustrated in Fig. 4. This shows the gloss image in Fig. 3 viewed as separate red, green, and blue components. It can be seen that the gloss characteristics are perceptibly different. Once again this raises the possibility that these gloss artifacts could be used as a machine readable security feature.

The images shown in Figs. 3 and 4 can be used to generate a crude measure of gloss color. The digitized images can be analyzed in various software programs and CIELAB information generated. However, as consumer digital cameras do not necessarily make accurate reproducible colorimeters, an alternative method was sought.

A Pye Unicam PU8800 UV/visible spectrophotometer was used fitted with a specular reflectance accessory (part no. 9423 179 082521). This accessory allows the specular reflectance of a sample to be measured over the entire visible spectrum over a range of angles of incidence from 15° to 75°. The resulting data could then be used to accurately calculate CIELAB color data.

Base line reflectivity was set to 100% on a front surface aluminum mirror and the following spectra were then recorded.

Figure 5 shows the specular reflectance spectra of the black ink used to generate Fig. 4, measured at 20%, 30%, 40%, and 100% ink loads.

These spectra illustrate the fact that the gloss color varies with ink load, as the curves are substantially different across the spectrum. This makes for an objectionable defect in photographic applications but a potentially valuable attribute in security printing, particularly for machine readability. A color filter could be used to render the detector sensitive to only one area of the spectrum.

Figure 6 illustrates one further artifact of this system, the issue of angle dependence.

In this case the same samples were measured again, this time at an angle of incidence of 10°. Comparison of Figs. 5 and 6 shows that the spectra and the resultant gloss colors are substantially different. Once again, this makes for an objectionable defect in photographic applications but a potentially valuable attribute in security printing as the geometry can be tuned for a particular ink/media machine readable system.

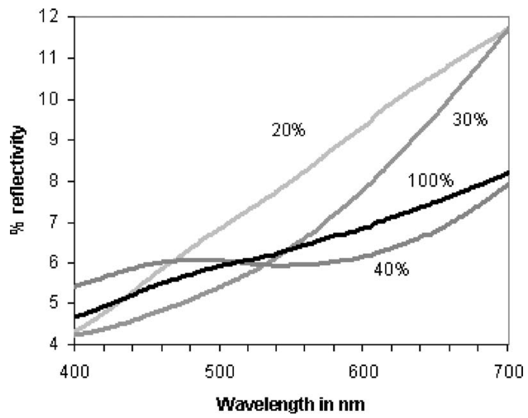

Figure 6. Specular reflectance spectra at 10°.

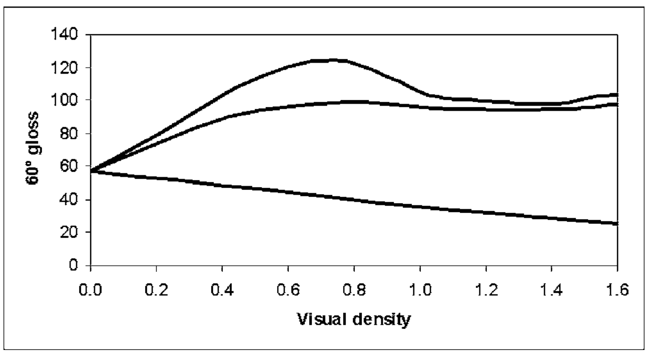

Figure 7. Black inks showing positive, negative, and complex differential gloss.

Gloss color appears to be intimately linked with differential gloss. It is prevalent in ink/media combinations showing complex differential gloss. Peaks in a plot of gloss against ink coverage (or density) coincide with high gloss color. Some of the reasons for this will be explored later in this paper.

One further cause of the variation of differential gloss with gloss color may be the spectral response of the gloss meter used. Gloss meters to ISO 2813 as used here measure visually weighted gloss to Illuminant C.[7] As gloss color changes with ink load this visual weighting will also result in different levels of measured gloss.

One further point of note is that the alternative method described in ISO 8254 measures visually weighted gloss to Illuminant A.[14] Colored gloss samples measured to these two standards are likely to be significantly different.

DIFFERENTIAL GLOSS VARIABLES FOR SECURITY PRINTING

There are a number of variables that influence these effects. These can be manipulated to give various attributes that are of use in security printing.

Some pigmented inks give much greater gloss effects others. This is illustrated simply in Fig. 7, which shows the gloss performance of three different pigment black inks on the same glossy microporous media.

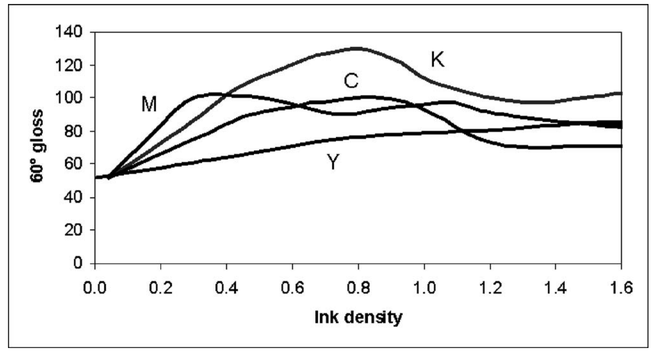

Figure 8. Gloss variation within a single ink set.

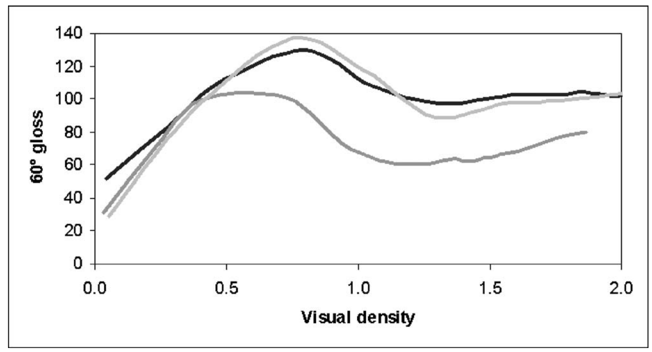

Figure 9. Effect of media type on gloss.

Even within a single ink set the gloss performance of the CMYK inks can be very different, as illustrated by Fig. 8. This shows that within this particular commercial ink set the curve shapes can be very different. While this can be a defect or artifact when inks of this type are used for photo-applications, it could be an attribute for security printing applications.

The issue of light inks is discussed more fully in a later section.

A much wider range of gloss performance can be achieved with judicious selection of inks. Figure 7 illustrates this using three different black pigmented inks to show positive, negative, and complex differential gloss on the same media!

The form of the gloss variation with printed density is also a function of the porous media type. This is illustrated in Fig. 9 which shows the same pigmented black ink printed on glossy porous media from three different manufacturers.

This variation with media type is an attribute as far as security applications are concerned as it adds another level of security against counterfeiting.

In practice it is very apparent that gloss color effects are very sensitive to the angle of incidence of the incoming light (I_{in} in Fig. 1). This is also illustrated by the differences in reflection spectra between Figs. 5 and 6.

As described above, the gloss meter used allows for measurements to be made at three angles of incidence. Figure 10 illustrates the effect of gloss angle on measurements of a pigment black ink.

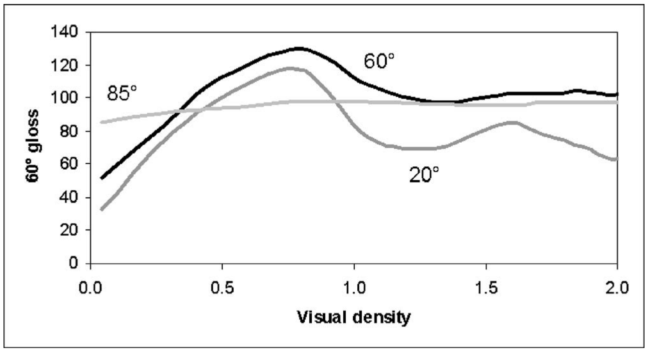

Figure 10. Gloss of black areas at different gloss angles.

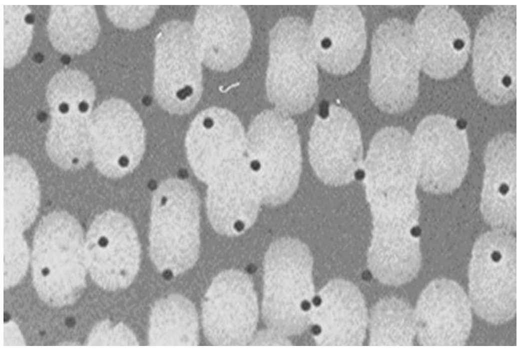

Figure 11. Reflection image of an ink/media combination.

OPTICAL FACTORS INFLUENCING GLOSS EFFECTS

The difference in optical reflectance characteristics between printed and unprinted areas is not the exclusive preserve of pigmented ink jet inks. It has also been shown to be the case for electrophotographic and lithographic prints.[17] However, the difference in reflection characteristics between media and ink is particularly pronounced in some of the combinations used in this paper. This is illustrated in Fig. 11, taken down a microscope. It shows an area of 20% ink load of the black ink giving complex differential gloss illustrated in Fig. 7. The image was taken with low (0.2) numerical aperture optics and therefore shows predominantly specular reflection. The black ink appears to be brighter than the white media because the ink spot has a high specular reflectivity.

The high specular reflectivity of the ink could arise from two possible causes:

1. The ink has a smoother surface than the surrounding medium. It has been shown that gloss is an inverse function of surface roughness.[23]
2. An optically thin film that enhances surface reflectivity covers the ink dots.

One way to separate these effects is to image the surface in a nonoptical manner such as with a scanning electron microscope (SEM).

Figure 12 shows that the printed area appears to be slightly rougher than the unprinted surface. This result, together with the observation that these inks exhibit strong gloss color (see above) leads to the conclusion that the enhanced reflectivity and the gloss color are a result of an optical thin film. However, we will return to the issue of surface roughness on a coarser scale later.

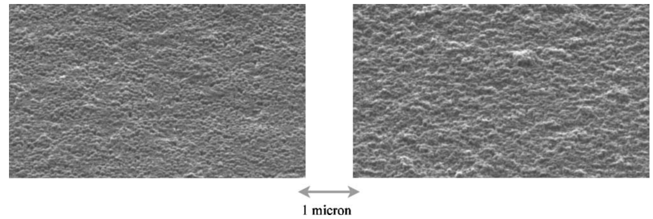

Figure 12. Unprinted and printed areas by SEM.

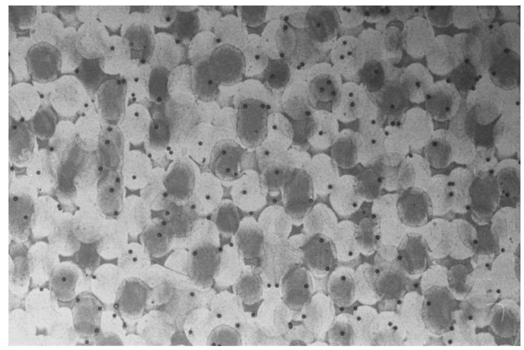

Figure 13. Reflection microscope image showing light and full black dots.

This theory of an optical thin film is given further credibility by other literature. A recent patent claims to have solved the smudge problem of pigmented inks by using a film-forming layer.[24] This film-forming layer may come from a resin incorporated in the ink or from fine (100–150 nm) self-crosslinkable polymer beads—the patent covers both.

This film-forming property, discussed in the literature[25] would be the cause of the optical thin film. It would explain the high specular reflectivity (gloss) of the ink spots illustrated above.

Finally, the thin film theory is further reinforced by lamination of the printed material. As this effectively index matches the surface of the print, gloss color effects disappear. The use of sealable layer technology[8] has the same effect for the same reasons.

The use of ink sets that contain both full strength and light inks give an additional and useful variable for security printing. This is because they can be formulated to give very different gloss characteristics.

This is illustrated in Fig. 13 by a microscope picture of a medium density black area consisting of a mixture of full and light black ink dots. Due to the increased concentration of pigment in the full black ink, the reflectivity of the dots (and, hence, the gloss) is lower. This increase in pigment concentration overwhelms the smoothness of the film formed by the ink. The capability to modulate gloss behavior by the judicious mixing of light and full ink components is another method of generating security artifacts.

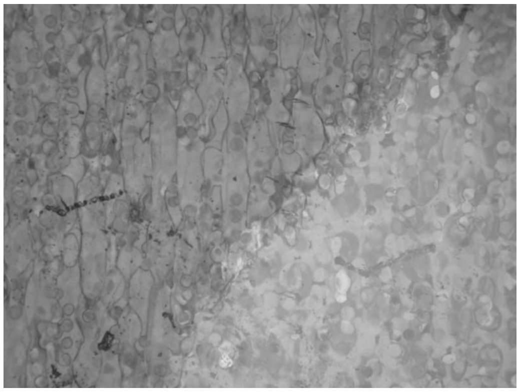

Figure 15. Reflection microscopy picture of laked ink.

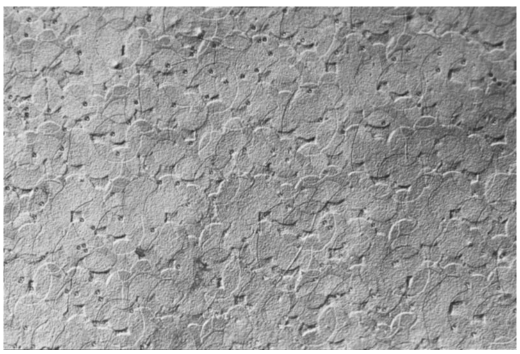

Figure 14. Reflection microscope picture of a high density area.

It should not be assumed that the complex differential gloss behavior of these inks is caused exclusively by the transition from light to full pigment strength as density increases. In this case the light black ink exhibits complex differential gloss when printed alone.

Finally, the surface behavior at high densities is a further variable that can be used as a security attribute. In some cases the ink leaves a surface relief at higher densities that is illustrated in the photomicrograph Fig. 14, taken using polarized light. Ink spots printed on top of each other is known to cause surface unevenness[26] and surface roughness a reduction in gloss.[23]

However, if the inks are formulated in a fashion that causes the dots to lake or flow together before drying a smoother, higher gloss is achieved at higher densities, as illustrated in Fig. 15.

CONCLUSIONS

Pigmented ink jet ink and media combinations can be formulated that can achieve distinctive gloss effects. These have potential applications in security printing.

Simple optical systems can be constructed that allow the visualization of gloss effects. These also provide a model for machine reading systems.

While the measurement of differential gloss is a known method in the literature methods of visualizing and quantifying gloss color have been demonstrated.

Reflection microscopy has been shown to be a useful method in demonstrating the cause of these gloss effects.

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The practical work in this paper was done while in the employ of Ilford Imaging UK Ltd. and is reproduced here with the permission of Ilford Imaging Switzerland GmbH.

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