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New luster formula for the characterization of hair tresses using polarization imaging

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Synopsis

Hair luster is one of the most important parameters of visual appearance perceived by consumers. Current luster formulae (TRI, Reich-Robbins, …) are optimized for goniophotometric measurements. They are based on a mathematical decomposition of reflected light into specular and diffused light and the meaurement of the shine peak width on the fitted angular distributions. In this expose, we are describing a polarization imaging system measuring luster of hair tresses with an innovative algorithm.

Using polarization imaging allows to physically separating the specular light from the diffused light for each pixel of the imaged tress. Angular distributions of the specular and diffused light are obtained in a few seconds. Where conventional methods calculate the shine peak width on the angular distribution, the imaging system imitates the human eye and calculates the shine width directly on the image.

The new formula combines different measured parameters to objectively quantify luster. It was designed to exhibit a higher correlation with visual perception along with a higher sensitivity. Results obtained with conventional formulae are compared on different hair tresses, treated and untreated. The new formula is found to be consistent for a whole range of hair colors, from light to dark.

INTRODUCTION

The analysis of hair visual appearance has become strategic for the hair care industry. It enables product efficacy evaluation, claims substantiation and improvement of hair product formulation. For a long time, the evaluation of the visual appearance of hair has been done by experts. In order to deliver more precise and objective data, quantitative techniques have been developed (1–3), mainly based on the measurement of the light scattered by hair fiber (individual or hair tress). Goniophotometer is an excellent example of a technique used for the understanding of hair visual appearance. Scientific method closer to what the human eye sees is often required and digital image of the hair tress has proved fundamental to analyze its visual appearance. Optical imaging system is very powerful because it can deliver both data and images in real time. Light scattering in hair fiber is complex and needs a detailed investigation. Polarization analysis is a well known technique to deeply analyze the composition of the light scattered by an object (1–9,15). This paper presents the application of a new polarization imaging technique for the measurement of hair visual appearance. A new luster formula enabling the characterization and the measurement on any type of hair is proposed.

SCIENTIFIC BACKGROUND

POLARIZATION OF LIGHT

Light can be described as an electromagetic vibrating wave that can be characterized by three main properties:

- Its intensity: it is related to the amplitude of the light vibration. The higher the amplitude of light vibration is, the more intense the light is.
- Its spectrum: it is related to the frequency or wavelength of the light vibration. In the case of visible spectrum, red has a greater wavelength than blue.
- Its polarization: it is related to the spatial orientation and coherence of the light vibration. Light can be either polarized (the light vibration has a defined orientation) or depolarized. In this case, the light vibrates randomly.

Along with intensity and spectrum, polarization of light carries abundant information (10–13) about the sample. Polarization is by far the less investigated of these three fundamental properties of light, mainly because of the lack of polarization sensor. However, polarization finds important applications for visual appearance measurement. One crucial property of polarization is the modification of the polarization of light after interaction with a sample. This modification allows characterizing the interaction. In the case of macroscopic objects, the type of interaction between light and matter can be separated into two main categories: coherent interactions and incoherent interactions (Figure 1). Coherent interactions preserve polarization of light. They include reflection and refraction at an optical interface. Incoherent interactions destroy polarization of light. They include scattering and diffusion. For instance, if the illumination is polarized, the reflected and refracted light will remain polarized while the scattered light will be depolarized. This fundamental property allows to measure independently the diffused light and the reflected light. The independent measurement of those two components is of prime importance for cosmetic evaluation.

INTERACTION OF LIGHT WITH HAIR FIBERS

Hair has a very specific visual appearance (3,4,8,9,14,15). Hair fibers can be considered as transparent and partially absorptive fibers with small steps at its surface due to the hair cuticle. This structure causes the visual appearance of hair fiber. It is widely accepted that hair visual appearance comes from 3 different interations of light with the hair fibers resulting in three components of light (Figure 2):

- The first component is called the shine band. It is caused by the reflection of the light on the surface of the hair fiber. Since this component consists of an external reflection, it remains polarized, it is "white" (more precisely of the same color as the illuminating light) and it appears as a band on the hair tress. The width of the band is determined by the roughness of the surface and the irregularities on the hair fibers. The cuticle angle induces a shift of the shine band from the direction a reflection would have on a fiber without cuticle.
- The second component is called the chroma band. It is caused by the refraction of the incident light in the hair fiber and the reflection on the back surface. Since this component only experiences reflections and refractions, it remains polarized. Since the

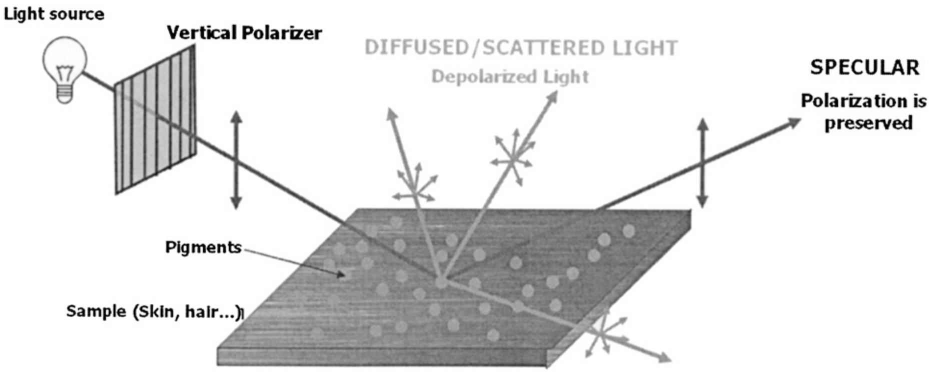

Figure 1. Polarization set-up. Given the type of interaction with a sample, a polarized light will either keep its polarization if it is refelected off the surface of the sample or will be depolarized if it is scattered by the sample.

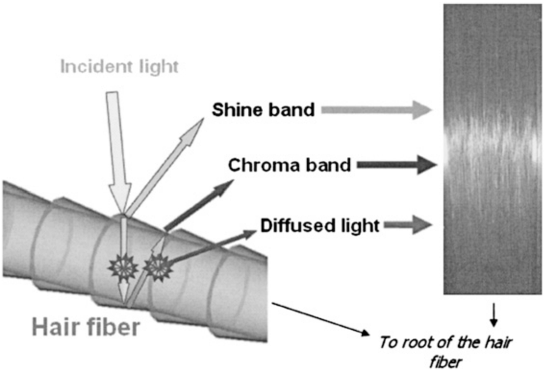

Figure 2. Interactions of light with hair fibers. The incident light on a hair fiber can be either: reflected by the surface of the fiber, which creates the shine band, or reflected after traveling through the fiber, which creates the chroma band, or scattered inside the hair fiber, which creates the diffused light.

light travels through the hair fiber, the chroma band is colored. Since this component is a reflection, it appears as a band on the hair tress. The width of this band is greater than the width of the shine band because it experiences the surface roughness of the hair fiber for one reflection and two refractions. The chroma band is also shifted by the cuticle angle in the direction opposed to the shine band.

- The last component is called the diffused light. It is caused by the light that is refracted into the hair fiber and scattered by pigments inside the hair fiber and other structural features of the cortex, like medulla. Since this component experiences diffusion, it is depolarized. Since the light travels through the hair fiber, it is colored. Finally, since it is caused by scattering, which is not a directive process, the diffused light does not appear as a band but as the background color of hair.

PRESENTATION OF THE SET-UP

A setup to measure independently polarized and unpolarized light component is designed. The setup consists of three main elements: a polarized illumination, a polarization camera and a cylinder on which the sample is positioned (Figure 3). Using both polarization camera and polarized illumination allows the independent measurement of polarized light and unpolarized light.

Combining a camera with a cylinder allows recording the angular distribution of the sample without any moving parts. Acquiring an angular distribution requires a change of geometric configuration of the group illumination-sample-observation. This change of configuration is created by the cylinder. The orientation relatively to the illumination direction and observation direction changes according to the point on the surface of the cylinder that is considered (Figure 4). The angle of the measurement is the angle between the direction of the specular light and the direction of observation. The angle between specular reflection and direction of obervation is the type of angle measured in goniophotometers. Imaging setup has the advantage of acquiring images that can be used as a direct visual control of the numerical data. Images allow understanding better how a change of certain parameters like a darkening of the diffused light or reduction of shine band width affect the visual appearance of the sample.

The use of both polarized illumination and polarization camera allows recording three types of images (Figure 5):

- A normal intensity image representing what a human eye would see.
- A specular image representing the light that is polarized. This polarized light shows only the reflections (first and second.)
- A diffused light image representing the light that is unpolarized. This unpolarized light shows only the light scattered inside the hair fiber. It is the background color of the hair.

Diffused light and reflections are physically separated without using any fits or mathematical decompositions. The computation of the angular profiles is done by averaging the images along the transverse direction (Figure 6). The system is angularly calibrated with its geometric properties so that the real angles are known for each line of the image. These angular profiles are similar to those provided by goniophotometers. From these profiles and images, relevant parameters characterizing the light distribution are computed. These parameters include: integral of the curve, maximum, width…

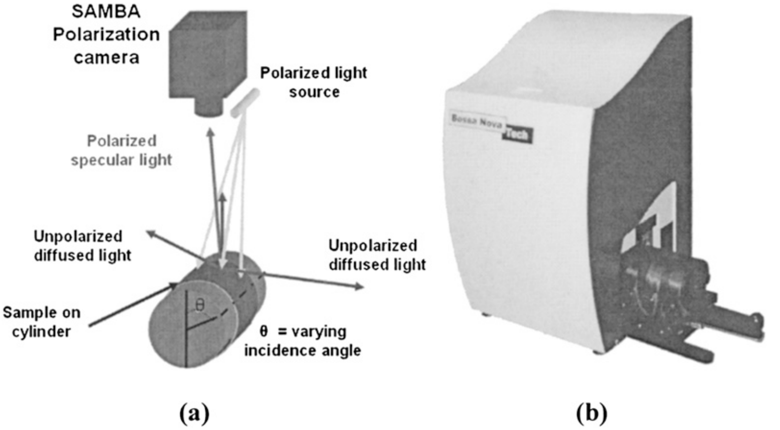

Figure 3. (a) Optical setup of the polarization imaging system. (b) Commercial system.

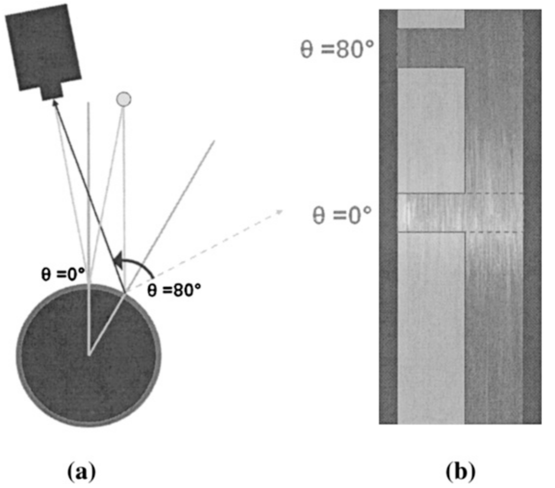

Figure 4. (a) Sample positioned on the cylinder. (b) Complete angular distribution with a single image.

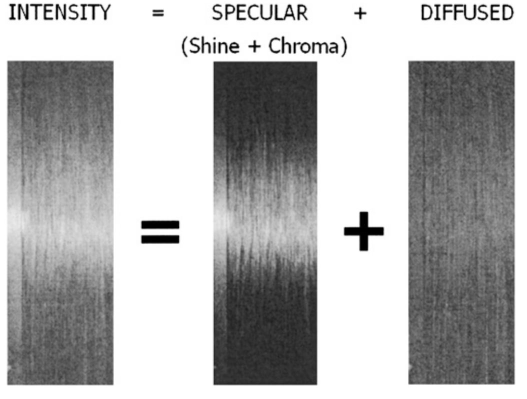

Figure 5. Three images are acquired: an intensity image showing the normal view of the hair, a specular image showing only the reflections (shine and chroma) and a diffused light image showing the diffused light only.

Polarization imaging provides the profile of intensity, specular and diffused light, as well as the corresponding images. These come from a direct measurement of a different physical property of light. Goniophotometric measurements only gives the profile of the intensity of light. Several methods like deconvolution and curve fitting allow extracting specular and diffused light from goniophotometric measurement.

The results obtained are very similar but also show some small difference. For instance, deconvolution or curve fitting methods usually consider the specular light to be zero outside of the main specular peak. Polarization shows that it is not always the case.

Having this physical separation allows better understanding of the effect of treatments. For instance, as specular light is considered to be zero outside of the main peak, a goniophotometric method will attribute a decrease in the edges of the intensity light distribution to a decrease of diffused light (meaning a darkening of the hair). Polarization meaurement allows saying if it comes from a decrease of the specular light outside of the main peak (meaning a reduction of the extreme surface defects that put specular light far from the main peak) or from a decrease of the diffused light (darkening of the hair).

Further processing on the specular profiles using RGB information allows separating the shine band from the chroma band (Figure 7). This separation is based on the fact that the shine band is white. This final separation allows complete characterization of the hair visual appearance. It shows that for light blond hair chroma totally dominates shine (Figure 8). In the case of light blond hair, the luster sensation comes mainly from chroma as the shine is negligible. It also shows that some treatment to increase shine overlaps shine and chroma which cause an increse of what is visually considered as the shine band but is actually shine and chroma.

It has been considered for a long time that only the first surface reflection was playing a role in hair luster. However these results as well as other recent research (16) show the

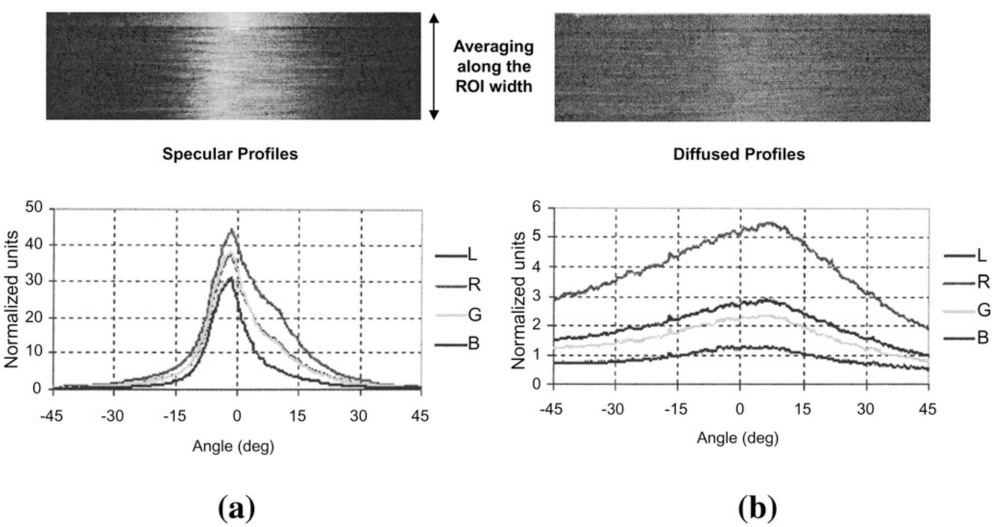

Figure 6. Angular profiles computed from the images acquired by averaging along the width of the region of interest (ROI). (a) Specular. (b) Diffused.

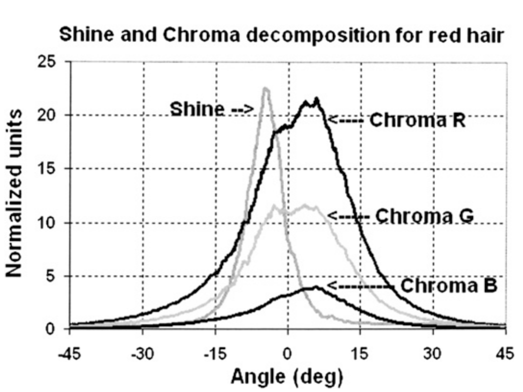

Figure 7. Extraction of the shine and chroma bands from the specular profile for a red hair. This separation is based on the fact that the shine band is white while the chroma band is colored.

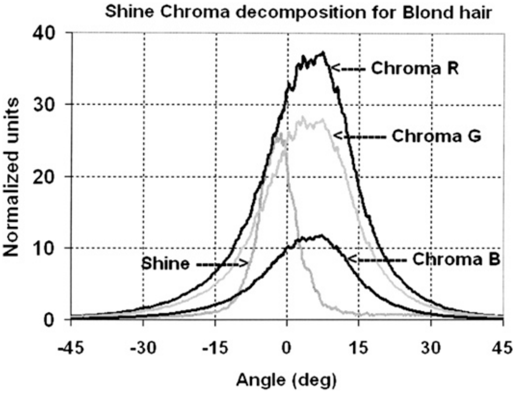

Figure 8. Extraction of the shine and chroma bands from the specular profile for blond hair. There is less shine than chroma. The chroma can be even higher for light blond hair.

importance of chroma in luster sensation. For instance, shine and chroma, which are both reflections, move along the hair fibers according to the direction of illumination and observation. This is typically observed for hair that is moving in the wind.

It seems that there is currently no consensus on the shine being the only component playing a role in hair luster. In our research, we consider them playing an equal role and use the whole specular light to estimate luster. This equal role is chosen as the eye cannot make the difference between shine and chroma when they are overlapped and for very blond hair.

Polarization which separates the reflections from the diffused light, simplifies the quantification of luster sensation.

LUSTER PARAMETER

Luster is a term used to describe the state or quality of shining by reflecting light. Luster qualifies the visual appearance of the object. It is strongly linked to the idea of quality and beauty of an object. Scientists have tried to compute a parameter that would quantify the visual luster sensation (1,2,8,17). But obtaining one number that quantifies the luster sensation is not straightforward. Luster is generally considered to depend on three main parameters (Figure 9):

- The amount of specular light. The more specular light there is, the higher the luster will be.
- The distribution/width of the reflected light. For a same amount of reflected light, the more defined and more concentrated the reflected light is, the higher the luster will be.
- The amount of background light on which the reflection is observed. The darker the background is, the more contrasted the specular light appears and the higher the luster.

Several luster formulae were developed and published by scientists using goniophotometers and other instruments to quantify human perception of Luster. The parameters used in the formulae are:

- S the total amount (integral) of the specular light
- D the total amount (integral) of the diffused light
- $\theta_{1/2}$ the width of the specular light distribution

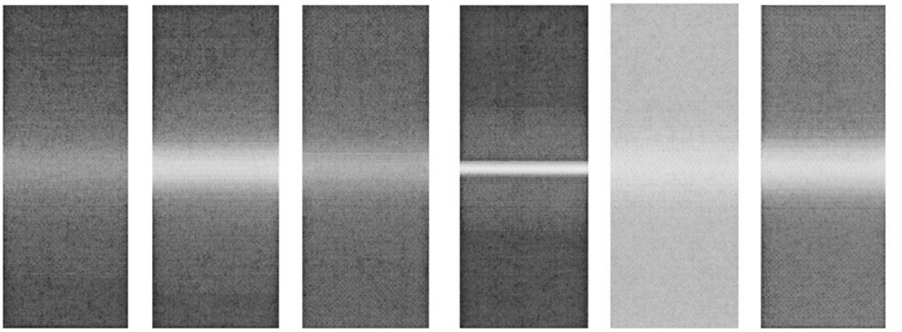

Figure 9. Luster is considered to depend on three parameters. (a) Increase of the amount of light reflected. (b) Reduction of the width of the specular light while keeping the overall amount of specular light constant, so light is more concentrated for a smaller width. (c) Increase of the diffused light (background) while keeping the reflected light the same.

The four most used formulae are the Reich-Robbins, TRI, Stamm and Guiolet formulae (Equations 1). Among these, Reich-Robbins and TRI formulae are the most used. For instance, Reich-Robbins is the direct mathematical translation of the three basic assessments about Luster. Reich-Robbins Luster is directly proportional to the amount of specular light S, so a two-fold increase of specular light results in a two-fold increase of Luster. It is also inversely proportional to the amount of diffused light, so if the background light is two times darker, the luster is two times greater. Finally, it is also inversely proportional to the angular width of the distribution so if the specular light width is divided by two, the specular light is twice as concentrated and the luster is two times greater. The TRI formula is similar to the Reich-Robbins one except that the diffused light is replaced by the specular plus the diffused light and that the luster is normalized by a reference angle. Stamm and Guiolet do not take into account the angular width of the distribution.

$$L_{Reich-Robbins} = \frac{S}{D * \theta_{1/2}} \qquad L_{TRI} = \frac{S}{S+D}\frac{\theta_{ref}}{\theta_{1/2}} \qquad (1)$$

$$L_{Stamm} = \frac{S-D}{S} \qquad L_{Guiolet} = \frac{S}{D}$$

Equations 1. The four most used luster formulae are the Reich-Robbins, TRI, Stamm and Guiolet formulae.

USE OF PREVIOUS LUSTER FORMULAE WITH POLARIZATION DECOMPOSITION

The previously described luster formulae were designed with mathematical separations of specular and diffused light (curve fitting and other deconvolution methods). They give results that are well correlated to the visual perception with goniophotometric measurements.

They can also be calculated with the physical separation of diffused and specular light distribution obtained with polarization. However, using these formulae, that were designed for goniophotometric measurement and mathematical decomposition, with the polarization decomposition can lead to results that are not correlated to the visual luster sensation. This is especially the case for very dark hair. The most obvious and problematic example with the previous formulae is for treatments on very dark hair.

For instance, shine treatments will provoke an important visual increase of luster, with the treated hair tress appearing to have more to much more luster than the same untreated sample according to most panelists (the results are detailed further in the article). In the case of our study, slightly more luster means less than 30% increase, more luster means about 50% more luster and much more luster means about or more than twice as much (100%).

However, the increase observed with the Reich Robbins and TRI formulae is moderate, only respectively of 16% and 27%. In some cases, usual formulae may only observe a few percents of increase while the visual difference is obvious. This shows that the luster formulae used with polarization have a highly decreased sensitivity to luster changes for very dark hair. We investigated the cause of this lack of sensitivity. For very dark hair, the diffused light is extremely low. As a matter of fact, even at the very edge of the distribution (high angles), the specular light is still higher than the diffused light. Considering the true polarimetric diffused light is not relevant in the case of very dark hair, for which the diffused light is negligible in front of the residual specular light located far from the specular peak. This is what causes the lack of sensitivity when the previous formulae are used with the true specular and diffused light measured with polarization. To keep a good sensitivity even when the diffused light is negligible, a new luster formula has been developed (Equation 2), named L_{BNT} (BNT for Bossa Nova Technologies). In this formula, the specular light is split into:

- S_{in}, that corresponds to the peak of the specular light and contributes to increasing the luster.
- S_{out}, that corresponds to the wings of the specular light (high angles) and contributes to decreasing the luster.

$$L_{BNT} = \frac{S_{in}}{(D + S_{out}) * W_{visual}} \tag{2}$$

Equation 2. New luster formula. The specular light is divided into two components and uses a visual width rather than a width measured on the profiles.

This decomposition is made using selection functions and not fits. The key to the sensitivity of the new luster formula is to choose the good combination of selection functions to obtain a high sensitivity and to measure relative increases that are correlated to the visual sensation. With the new formula, larger increases of luster are observed than with other formulae on dark hair. The observed increases are in the same order of magnitude as the increase observed by panelist.

CALCULATION OF S_{in}

Several types of selection function can be used to get S_{in} (Figure 10). The most simple is a rectangle function. The advantage of a rectangle function is that it has a flat top so it keeps the exact shape of the specular peak. However it has a straight cut at the edges. To avoid this straight cut, Gaussian function can be used. The disadvantage of Gaussian function is the rounded top which makes the shape of S_{in} different from the specular peak.

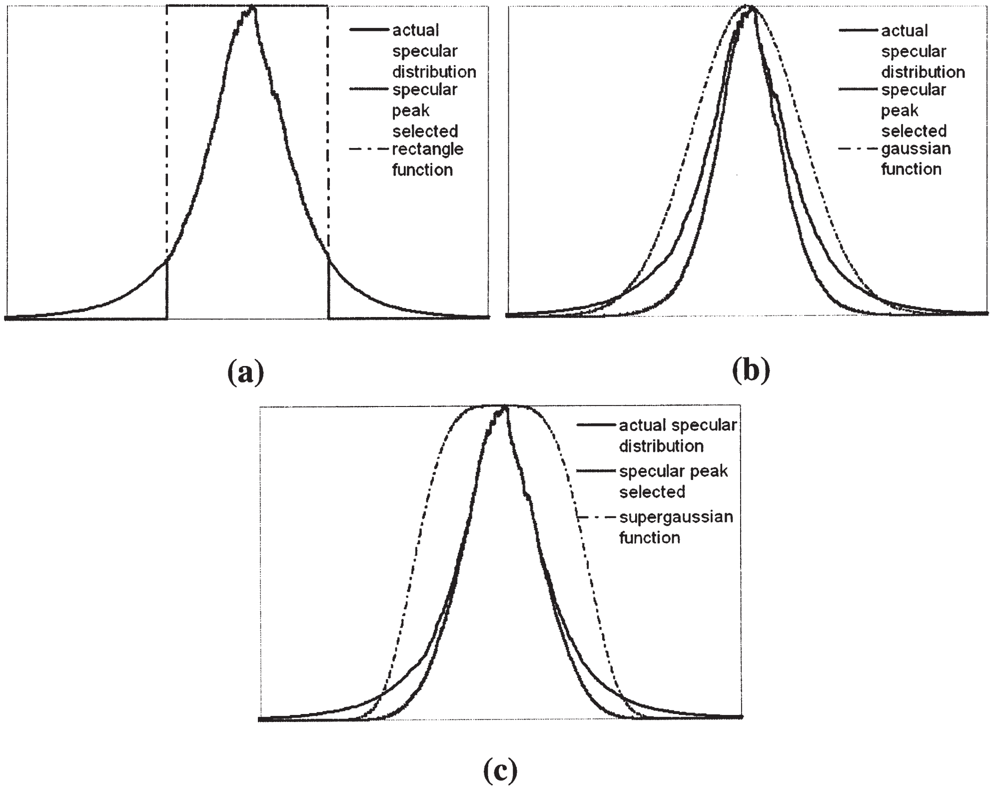

Figure 10. The peak of the specular distribution can be selected using different selection functions. (a) Using a rectangle function creates straight edges but the peak selected has the same shape as the specular profile. (b) Using a Gaussian function does not create straight edges but the peak selected does not follow the same shape as the specular profile. (c) Using a supergaussian function combines the advantage of rectangle and Gaussian function.

The selection function used to isolate S_{in} in the specular light is a supergaussian function. Supergaussian has a flat top and no straight cut at the edge and so combines at the same time the advantage of rectangle function and of Gaussian function. It makes physical sense to keep the exact shape of the peak while avoiding straight edges. Other selection function could give better results but the supergaussian has the advantage of being simple while having a physical meaning. This is the reason why the supergaussian has been chosen.

A supergaussian function is defined by its width and its position. The FWHM (full width half maximum) of the selection function is twice the FWHM of the measured specular profile. The selection function is centered on the same point as the specular light distribution. Then the selection function and measured profile are multiplied together which gives the S_{in} signal. The algorithm steps to calculate S_{in} are summarized below:

- Measurement of the maximum value of the specular profile.
- Measurement of the FWHM of the specular profile and position of the profile by computing the center at the location of the FWHM. The center is not the position of the maximum if the profile is skewed.

- From the FWHM and position of the profile, the selection function is calculated.
- Selection function and profiles are multiplied to get S_{in} signal.

These steps are summarized in Figure 11.

CALCULATION OF S_{out}

The selection function to isolate S_{out} is of the form 1-supergaussian. Many types of supergaussian functions have been tested to obtain the best sensitivity. The simplest solution would have been to take all the light that was not considered to be part of S_{in}. However, we observed that this leads to relatively moderate increase sensitivity. This is caused by the intermediate part between the wings and the peak of the specular profile which has a behaviour close to the one of the peak and dominates the S_{out} signal as it contains much more light that the far wings. After testing several cases, it was observed that the sensitivity was increased when S_{out} was taken further from the specular peak. In this case, some of the specular light is considered neither in S_{in} nor in S_{out}. As S_{out} is observed only in the wings while the diffused light is observed for all the angles, the ratio of S_{out} and the

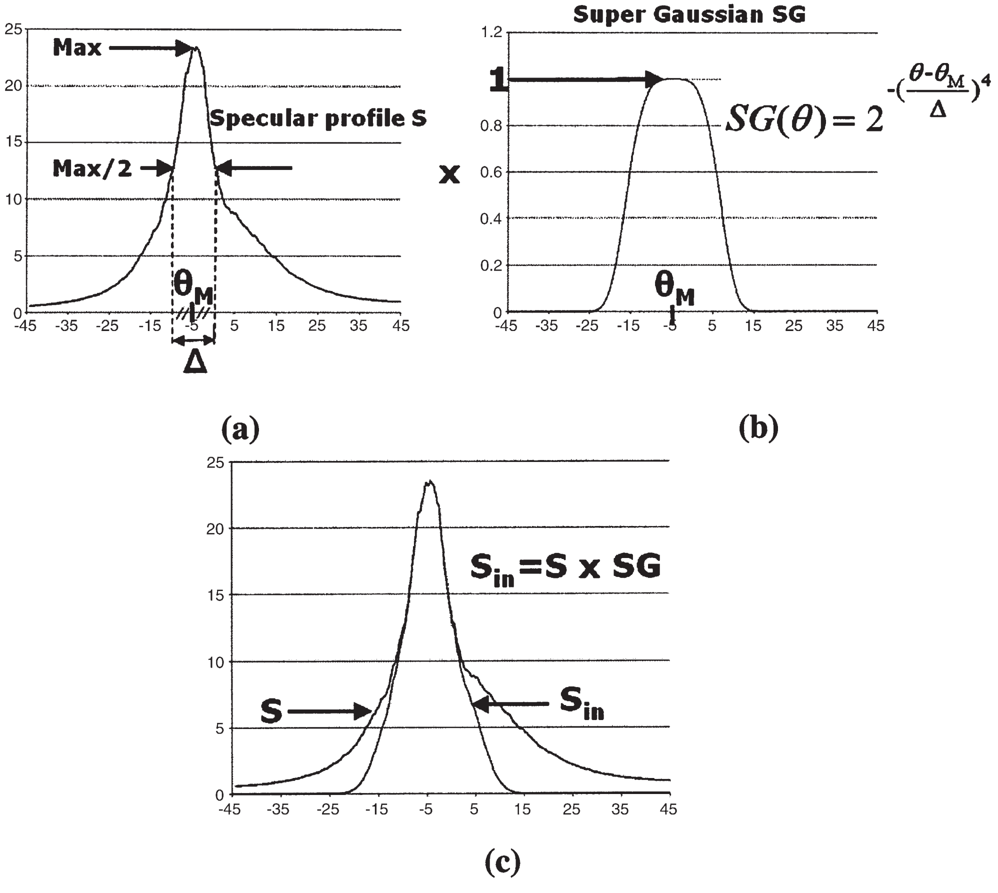

Figure 11. Extraction of S_{in} from the specular profile. The selection function is calculated (b) with the parameters computed (a) from the specular light distribution. Multiplying the selection function and the specular light profile gives the S_{in} profile (c).

diffused light is not the ratio on the height of S_{out} and Diffused light in the wings of the distributions. S_{out} has to be multiplied by a constant to keep the ratio observed in the wings. Otherwise, the influence of S_{out} would be underestimated compared to the influence of D (Figure 12).

VISUAL WIDTH OF DISTRIBUTION (W_{visual})

Among the advantages of polarization imaging, one is that images are available. Instead of measuring the width of the specular light on the distribution, the width is measured on the images, which permits to follow the band as the eye does (Figure 13). It keeps the advantage of averaging along multiple fibers while limiting the effect of misalignment and bad combing. The effect of following the band is particularly important for dark hair which does not show chroma. In the case of dark hair, the shine band can be narrower than the displacement of the band caused by combing. Measuring the shine band width on the image helps reducing the combing effect for dark hair. For hair that shows a large width

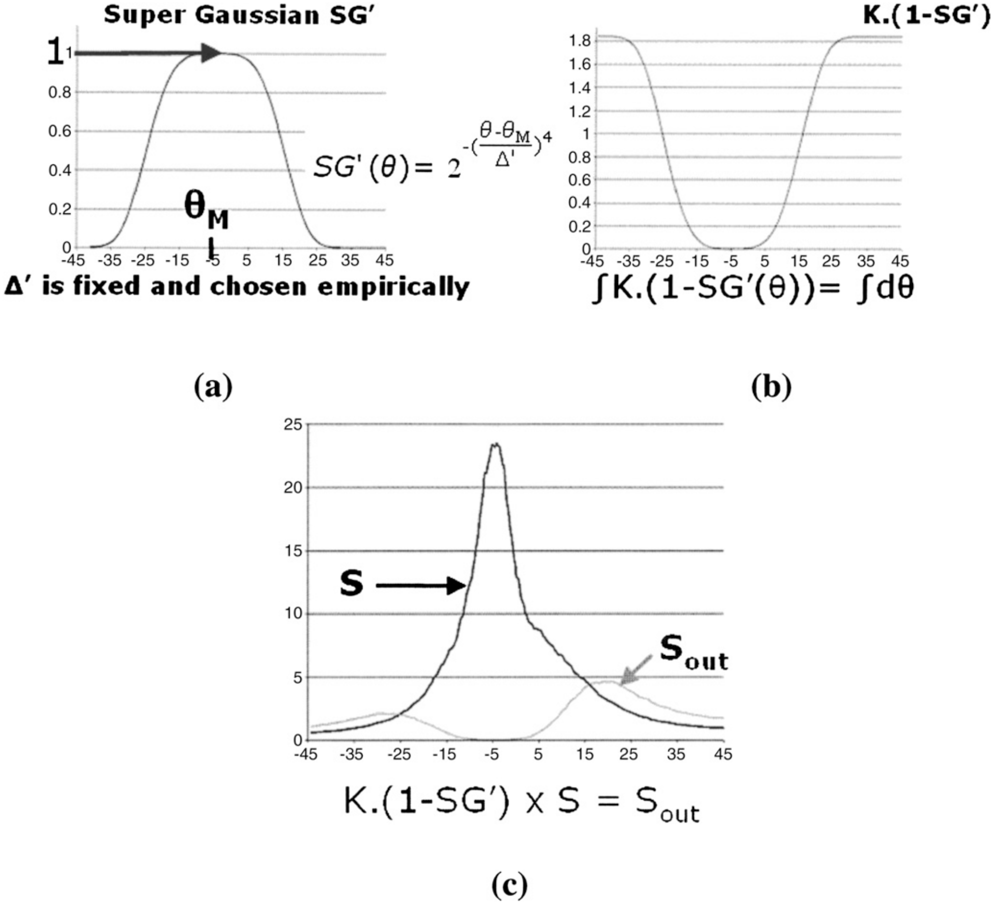

Figure 12. Extraction of S_{out} from the specular profile. The selection function (b) is calculated with the parameters computed (a) from the specular light distribution. Multiplying the selection function and the specular light profile gives the S_{out} profile (c).

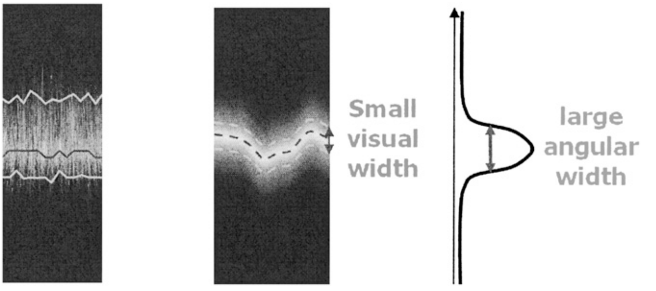

Figure 13. On very dark hair that is not perfectly combed, the visual width can be significantly narrower than the width measured on the profiles. This also partly explains the lack of sensitivity observed for very dark hair.

because of the chroma band (red and blond hair), measuring the width on the image does not significantly change the results.

EXPERIMENTAL RESULTS

The optical set-up has been tested on different type of hair in order to validate the new luster formula. 8 panelists have been asked to judge the increase of luster observed between an untreated and treated hair tresses put side by side. They have been asked to decide which sample had more luster. If they can decide, they check same luster. If they see a difference, they have to decide between 3 choices:

- slightly more luster (less than 30% increase)
- more luster (about 50% increase)
- much more luster (about or more than twice as much luster)

The hair tresses are 8 inch long and 3.5 g. The hair sample was treated with a silicon shine spray.

MEASUREMENT ON BLACK HAIR

Most of the panelist estimated the treated sample to have more or much more luster which corresponds to an increase clearly higher than 50% (Table I).

The effect of the treatment can be clearly observed on the images, the treated sample being darker outside the peak of the distribution (Figure 14). However this darkening is mostly in the specular light and not in the diffused light. Reich-Robbins and TRI formulae give respectively a 16% and 27% increase of luster which is clearly much less than the visual sensation. Bossa Nova Technologies formula gives a 116% increase of luster, which

Table I
Results of the Panelist Rating of Treated Versus Untreated Samples

	Same luster (*less than 10% increase*)	Slightly more luster (*less than 30% increase*)	More luster (*about 50% increase*)	Much more luster (*about or more than twice as much luster*)
Percentage of panelists	0%	12%	38%	50%

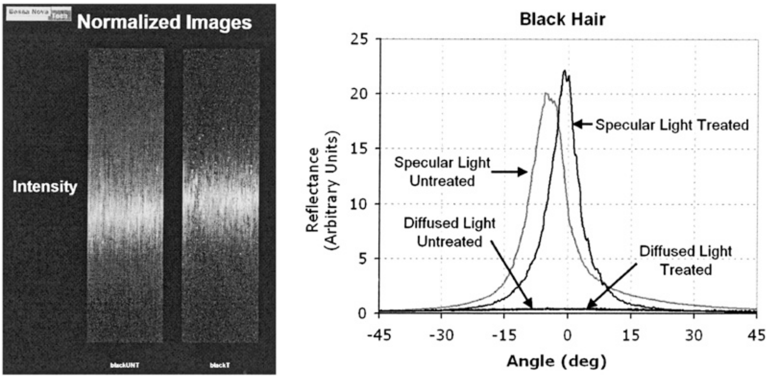

Figure 14. Images and profiles of untreated and treated black hair. The treatment increases the peak of the distribution and decreases the light in the wings of the distribution. The contrast of the treated sample is much higher as seen on the images.

is much more correlated to the visual change than the increase observed with Reich Robbins and TRI formulae.

On black hair, the diffused light is negligible in front of the wings of the specular light. So in the Bossa Nova Technologies formula, $D + S_{out}$ can be approximated to S_{out} (Equation 3). In this case, the Bossa Nova Technologies luster formula becomes a spatial contrast luster formula with the luster being the ratio of the light in the peak of the specular light over the light in the wings of the specular light.

$$D \ll S_{out} \quad L_{BNT} = \frac{S_{in}}{(D + S_{out}) * W_{visual}} \sim \frac{S_{in}}{S_{out} * W_{visual}} \tag{3}$$

Equation 3. Experimental results on dark hair. D is negligible in front of S_{out}. The Bossa Nova Technologies formula can be simplified to a spatial contrast formula.

MEASUREMENT ON RED HAIR

Most of the panelist estimated the treated sample to have more luster which corresponds to an increase higher than 50% (Table II).

The effect of the treatment can be clearly observed on the images (Figure 15). Shine and chroma bands are superimposed after the treatment which leads to smaller width of the distribution and higher contrast between the peak of the distribution and wings of the distribution. Reich-Robbins and TRI formulae give respectively a 63% and 34% increase of luster, which is less than the visual sensation for the TRI formula but consistent with the visual sensation for the Reich Robbins formula. Bossa Nova Technologies formula gives an 85% increase of luster which is also coherent with the visual change observed. On red hair, the diffused light is about the same level as the wings of the specular light. The Bossa Nova Technologies formula cannot be simplified (Equation 4).

$$D \sim S_{out} \quad L_{BNT} = \frac{S_{in}}{(D + S_{out}) * W_{visual}} \tag{4}$$

Equation 4. On red hair, S_{out} and D are of the same order of magnitude.

Table II
Results of the Panelist Rating of Treated Versus Untreated Samples

	Same luster (*less than 10% increase*)	Slightly more luster (*less than 30% increase*)	More luster (*about 50% increase*)	Much more luster (*about or more than twice as much luster*)
Percentage of panelists	0%	12%	63%	25%

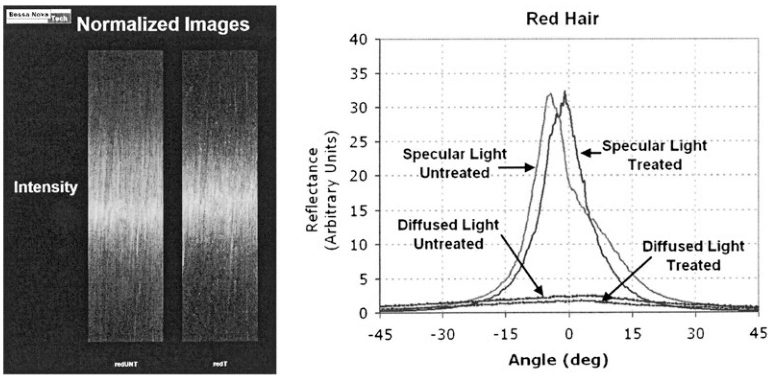

Figure 15. On red hair the effect of the treatment is to superimpose shine and chroma bands and to darken the outside of the distribution. Visually the contrast is also strongly increased.

MEASUREMENT ON BLOND HAIR

Most of the panelist estimated the sample to have much more luster which corresponds to an increase clearly higher than 50% (Table III).

Again the effect of the treatment is to superimpose shine and chroma band and to darken the wings of the specular distribution (Figure 16). Reich-Robbins and TRI formulae give respectively 80% and 44% increase of luster, which is respectively coherent and less than the visual change observed. Bossa Nova Technologies formula gives a 110% increase of luster which is also coherent with the visual change observed. On blond hair and very light hair, the wings of the specular light are negligible in front of the diffused light. So in the Bossa Nova Technologies formula, $D+S_{out}$ can be approximated to D. In this case the Bossa Nova Technologies luster formula becomes equivalent to the Reich-Robbins formula (Equation 5).

$$S_{out} \ll D \quad L_{BNT} = \frac{S_{in}}{(D + S_{out}) * W_{visual}} \sim \frac{S_{in}}{D * W_{visual}} \tag{5}$$

Equation 5. On blond hair, S_{out} is negligible in front of D, so Bossa Nova Technologies formula can be simplified to a Reich-Robbins formula.

DYNAMIC RANGE AND SENSITIVITY

By their definition, TRI, Reich Robbins and BNT luster formulae give a high luster value to dark samples. We compared the luster values given by the different formulae for the untreated black and blond hair samples (Table IV). While the Reich Robbins luster

Table III
Results of the Panelist Rating of Treated Versus Untreated Samples

	Same luster (*less than 10% increase*)	Slightly more luster (*less than 30% increase*)	More luster (*about 50% increase*)	Much more luster (*about or more than twice as much luster*)
Percentage of panelists	12%	0%	38%	50%

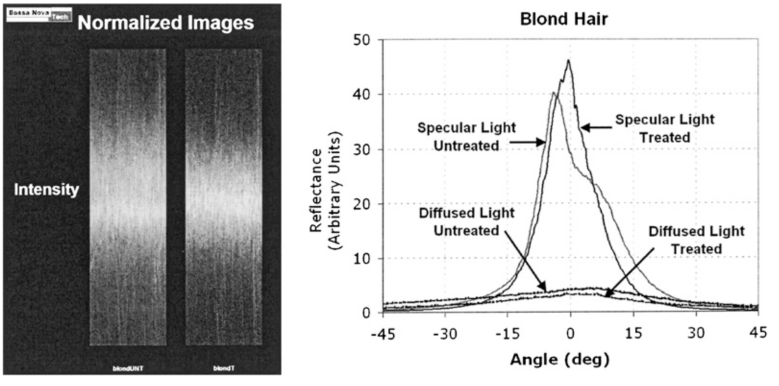

Figure 16. On blond hair the effect of the treatment is the same as on red hair. Visually the contrast is also strongly increased.

Table IV
The Luster Range of BNT Luster Is Similar to the TRI Formula While Having More Sensitivity

Luster formula	Reich-Robbins	TRI	BNT
Black	169.2	25.0	27.6
Blond	31.1	11.8	12.8
Ratio	5.4	2.1	2.2

is as much as 5 times higher for black hair compared to blond hair, TRI and BNT luster is only twice as much for black hair compared to blond hair. BNT Luster has an increased sensitivity to treatments on hair with no artificial luster range dilatation. The Luster sensitivity is increased while keeping the variations of luster for the different hair tress in the same order of TRI formula.

CONCLUSIONS

We have experimentally validated the polarization imaging technique to quantify the visual appearance of hair. Polarization enables an accurate and physical decomposition of the true diffused light. This decomposition is a powerful tool to improve hair visual appearance characterization and to better understand the effect of treatments. This technique delivers data and images related to the human visual assessment. Based on luster formulae developed mainly for photogoniometer, we introduced a new luster formula adapted to the polarization analysis. This new formula is a modified Reich-Robbins formula. It gives a high dynamic range and high sensitivity to small changes of luster. This new luster permits measurement of every type of hair. It gives improved results in terms of dynamic for dark hair and converges toward Reich-Robbins and TRI formulae for light hair. The combination of the polarization imaging technique and the new luster formula leads to a complete measurement of hair visual appearance.

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