Optical Characterization of Scattering Anti-Glare-Layers

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Optimization of visual performance of display systems

➔ **reduction of disturbing reflections**.

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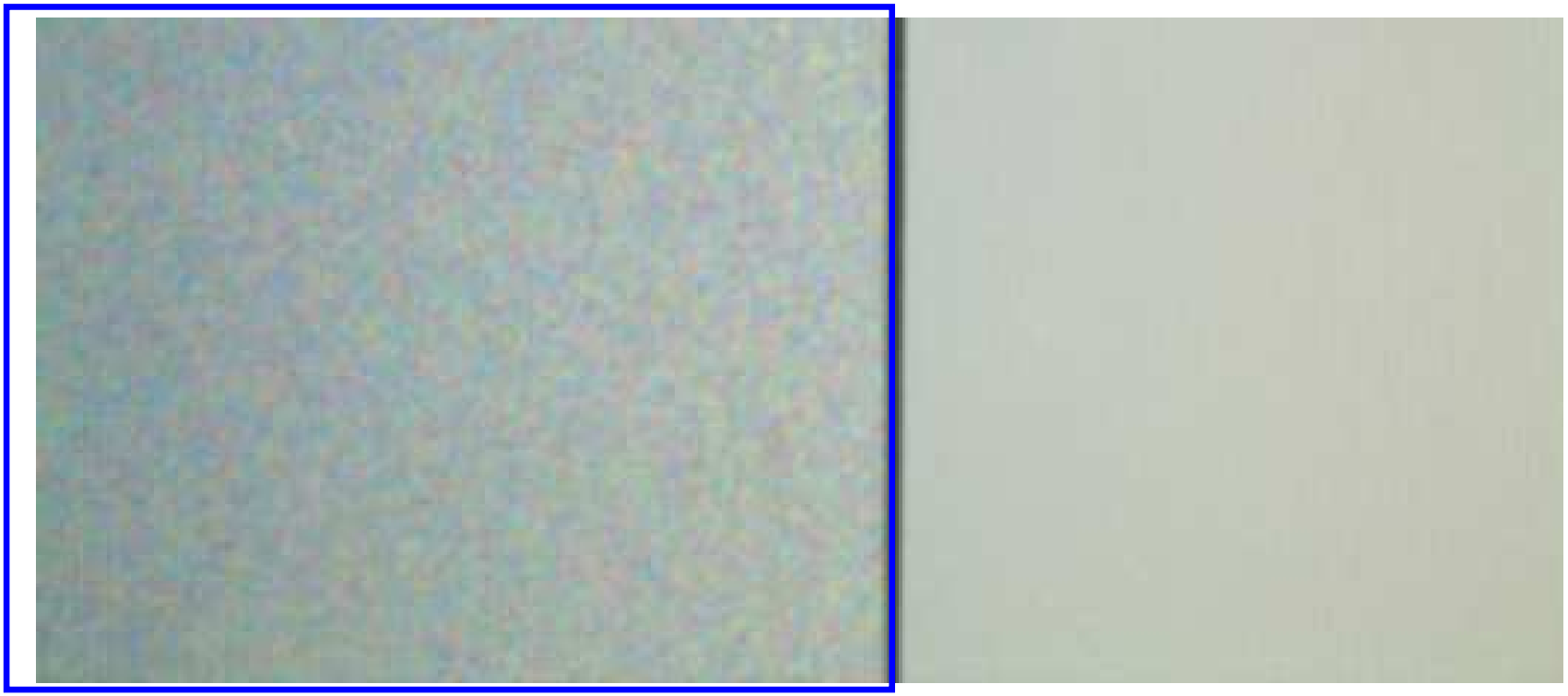
Sparkle ?

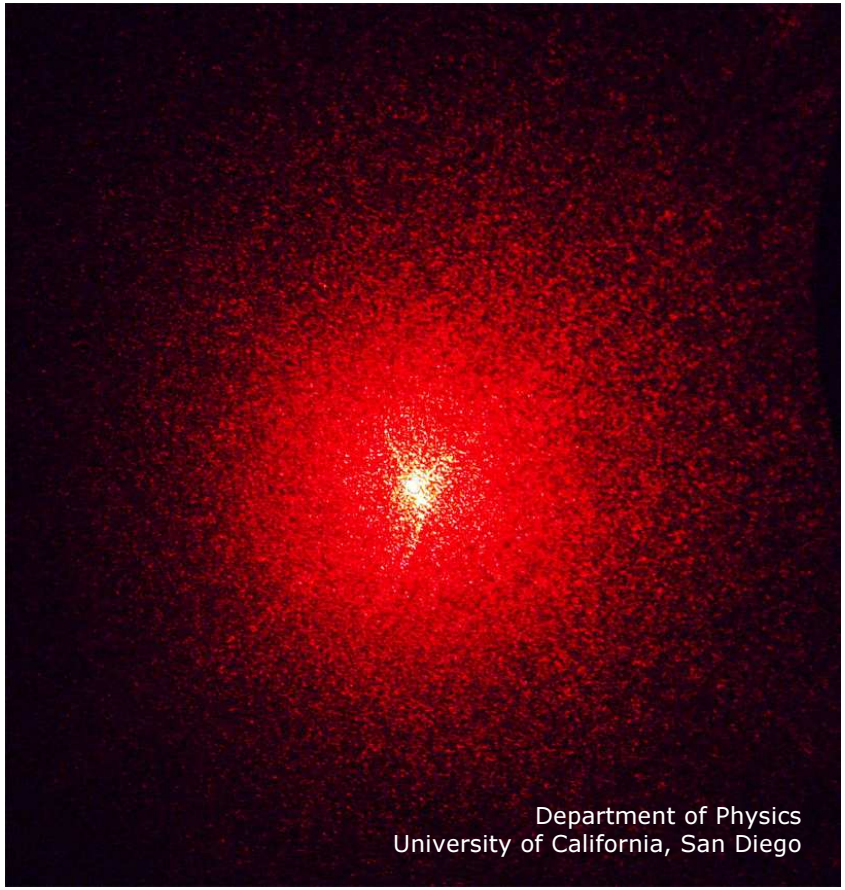


LCD-screen with AG-glass | without AG-glass

Sparkle obtained from a glossy LCD-monitor (plain white image) and a scattering AG-cover glass, a kind of "visual noise".

Intensity, color, and location of *sparkle* dots change with direction of observation.

Speckle ?



Speckle pattern obtained with laser light transmitted through a scattering anti-glare treated glass.

Speckle:

intensity pattern produced by interference of a set of wavefronts.

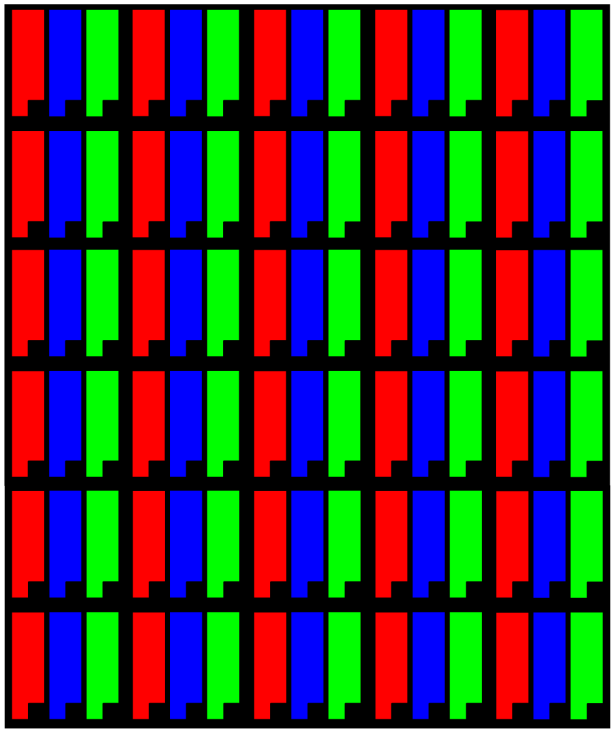
Intensity varies randomly and as a function of observation conditions.

Origins of sparkle

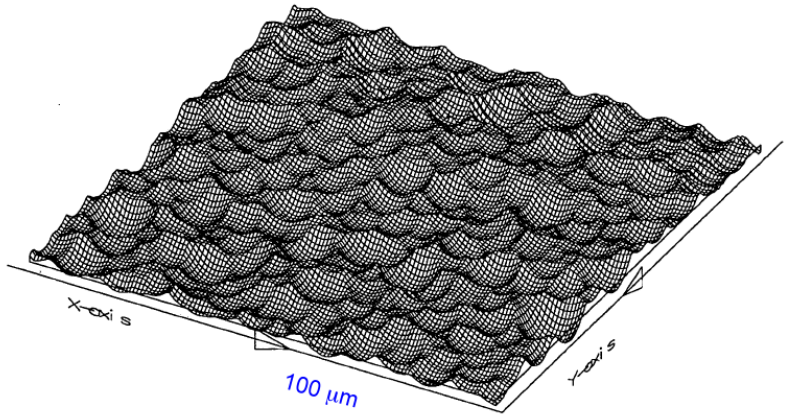
Result of the interaction of light with ***two structured surface areas***:

- the regular display pixel matrix (light source) and
- the anti-glare surface with irregular microstructures.

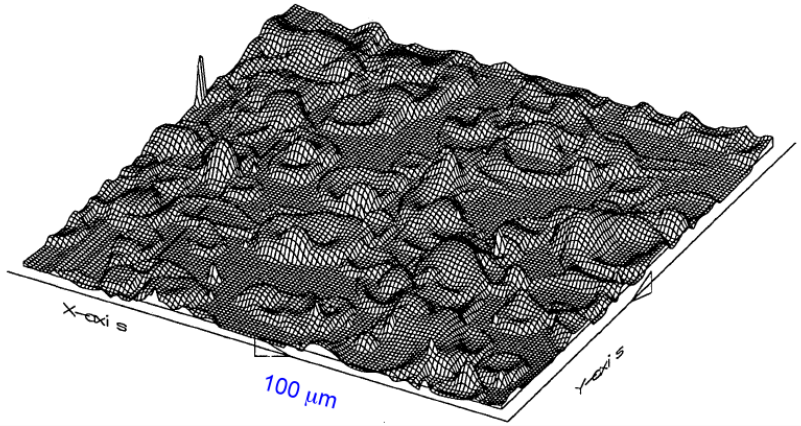
Refraction, diffraction and scattering of light all seem to be involved in the formation of the visual ***sparkling*** under discussion here.



Pixel matrix



Nuijs, Horikx, Applied Optics 33,18(1994)p.4058

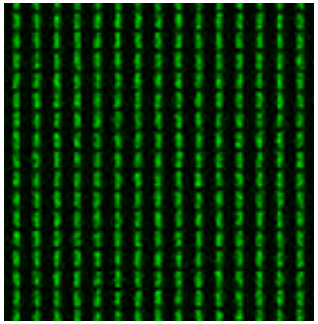


AG surfaces

Perception of sparkle

On a plain white display:
multitude of twinkling dots with different colors and intensities and a random distribution across the display area.

Sparkle pattern: sensitive to the direction of observation (sensitivity more pronounced in the direction perpendicular the long axis of the sub-pixels of the display).



On a monochromatic display:
random arrangement of tiny bright and dark dots.

Effect of viewing distance:
- visibility of the (sub)-pixels of the display matrix varies,
- perception of sparkle does not vary notably.

Binocular observation:
dots are most distinct when the eyes are not focused on the display surface.

Monocular observation:
small patches (granules) with irregular organic (cell-like) boundaries.

Wedge configuration: staircase pattern of stripes (binocular observation only).

Measurement and Control of Sparkle

Visual sparkle

on screens with scattering matted anti-glare layers (e.g. touch sensitive panels),

- twinkling of the image,
- especially distinct when the head of the observer is moving.

Focussing problems and eye-strain claimed by sparkle ...

Effect of display resolution

With increasing resolution of advanced display screens e.g. for mobile handheld devices (100 - 300 dpi) the problem becomes even more severe.

Visual Ergonomics

Reduction of the reflectance of disturbing ambient light sources remains important, since especially mobile devices are often operated under conditions without direct control of the illumination (e.g. outdoors).

Optimization of display systems with respect to visual performance:

- minimization of reflectance of ambient light sources, and
- suppression of distinct images of ambient light-sources (fusion conflicts),
- AG-layer should not affect the distinctness of the image,
- **control of disturbing sparkling effects.**

Measurement Setup

- electronic camera (1300 * 1000 pixels without color filters), 12 bit digitization,
- magnification in the range of 5 - 25 camera pixels per display pixel,
- working distance: between 15 cm and 70 cm,
- **reproduction of actual application situation:** LCD-monitor with a glossy screen as light-source,
  - typically monochromatic / green,

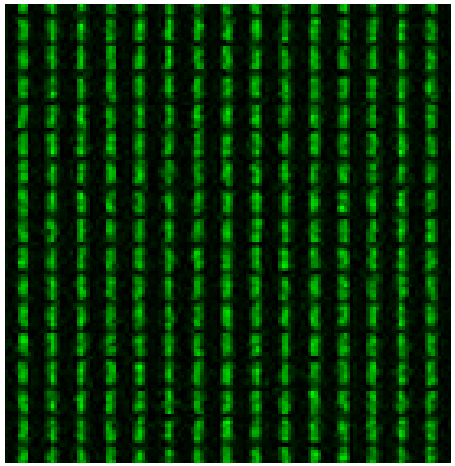
- AG-treated glass sheets on top.

Sparkle Evaluation

Basic problem:
separation of the statistic intensity modulations (sparkle) from the regular ones (display pixel matrix).

Two alternative approaches:

difference and filter method.



***Sparkle*:** $\mathbf{s = \sigma / \mu}$

σ: standard deviation of intensity

μ: mean value of sparkled image

Difference Method

Image aquisition

- record first image,
- slightly shift AG-glass laterally,
- record second image.

Evaluation

- Subtract one image from the other.

original image

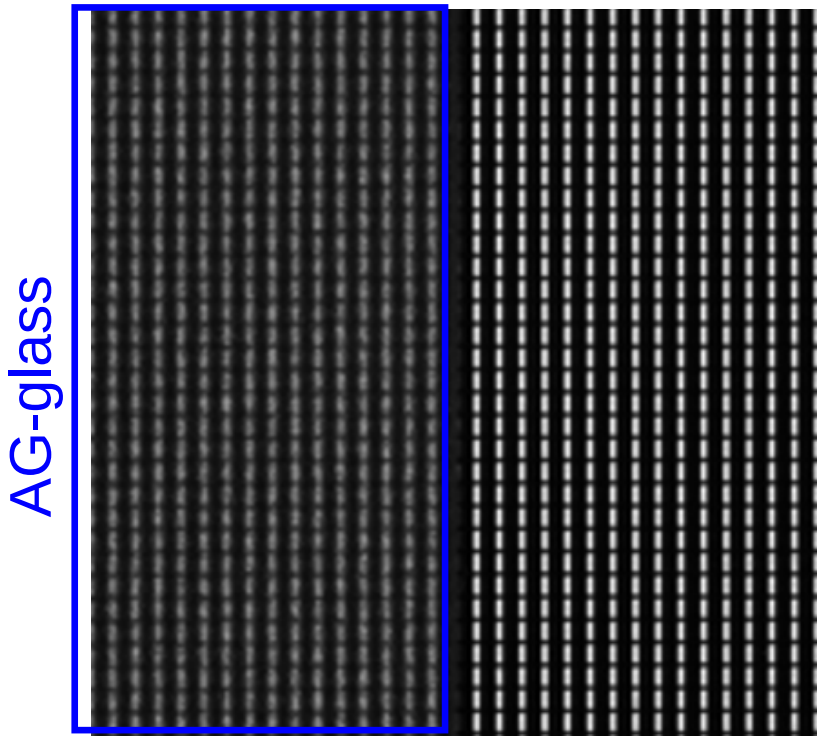
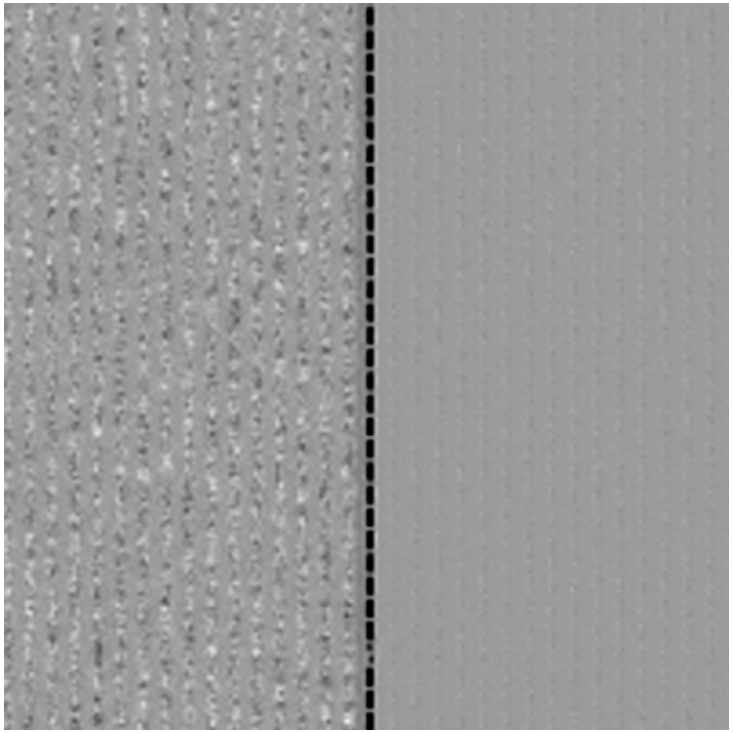


Image of AG-layer on top of display surface covering half of the region of interest (left half). The right half is the bare LCD-screen.

difference image



Regular intensity modulations removed by image subtraction. Sparkling becomes obvious in the left half of the image.

Filtering

Single image alternative: may be advantageous, since no mechanical interference (shifting of the AG-layer) is required.

Extraction of sparkling by appropriate spatial filtering, i.e. with masking in Fourier space.

original image

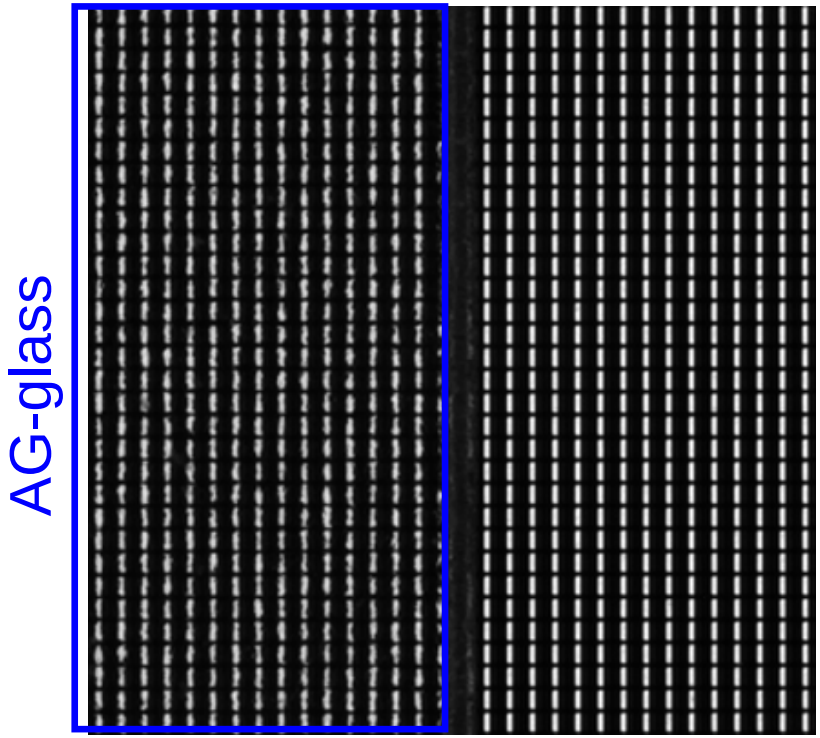
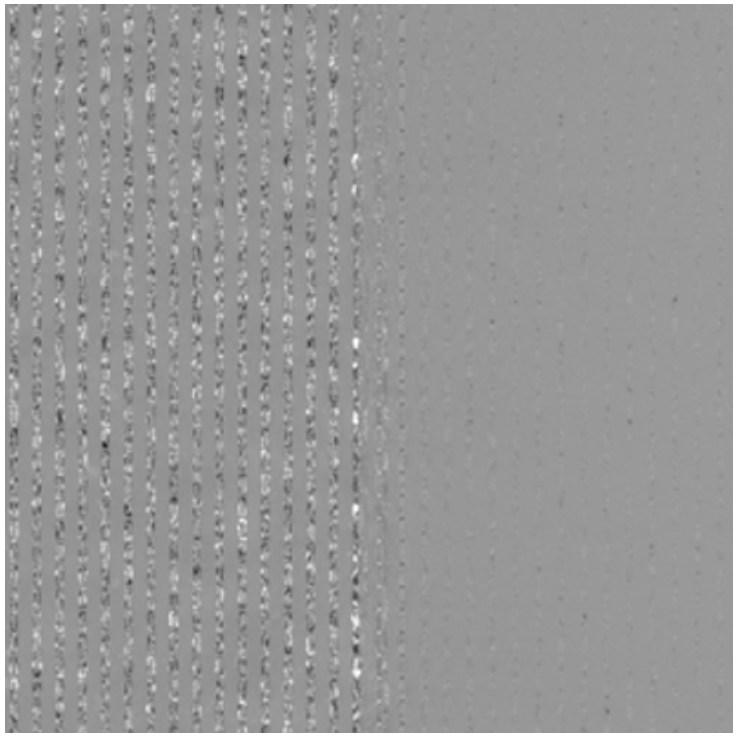


Image of AG-layer on top of display surface covering half of the region of interest (left half). The right half is the bare LCD-screen.

filtered image

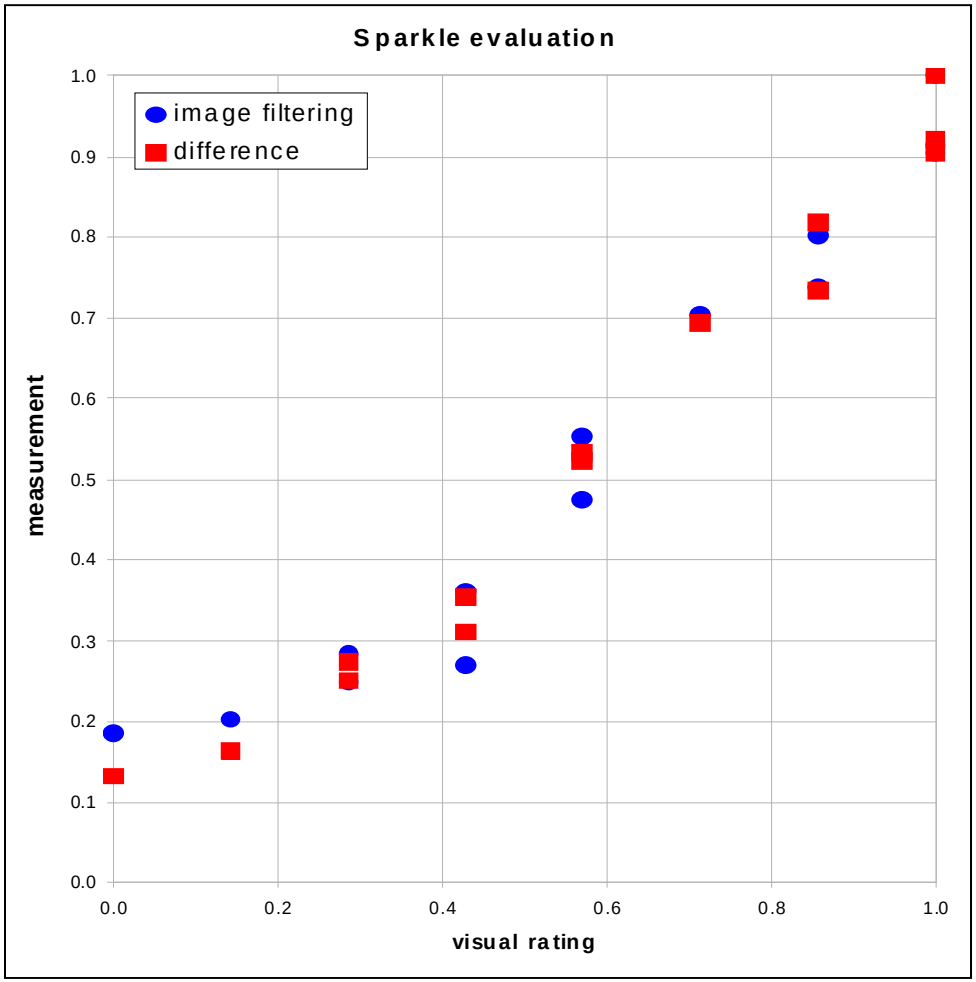


Regular intensity modulations removed by image spatial filtering. Sparkling becomes obvious in the left half of the image.

Results

Comparison of measurement and visual rating of expert observers to check the validity of the measurement method:

- The difference method accurately reproduces the ranking sequence of the observers.
- The filter method, in some cases, still reverses the ranking sequence.



Sparkle values (normalized) from **difference and filter method** for **14 samples** compared to (normalized) visual rating of expert observers (8 categories).

Reduction of Disturbing Reflections

Avoiding glare and fusion conflicts:
➔ optimized scattering anti-glare layers.

Evaluation of reduction of reflected light intensity:
bidirectional reflectance distribution function (BRDF).

Simplified BRDF method integrated in our measurement setup.

Characterization of Scattering

Illumination: linear light source (CCFL)
Intensity of reflected light recorded as a function of the location on the display.

Shape of the intensity curve:
scattering characteristics of the AG-layer.

Anti-reflection factor AR = $\max(L_{AG}) / \max(L_{LCD}) < 1$

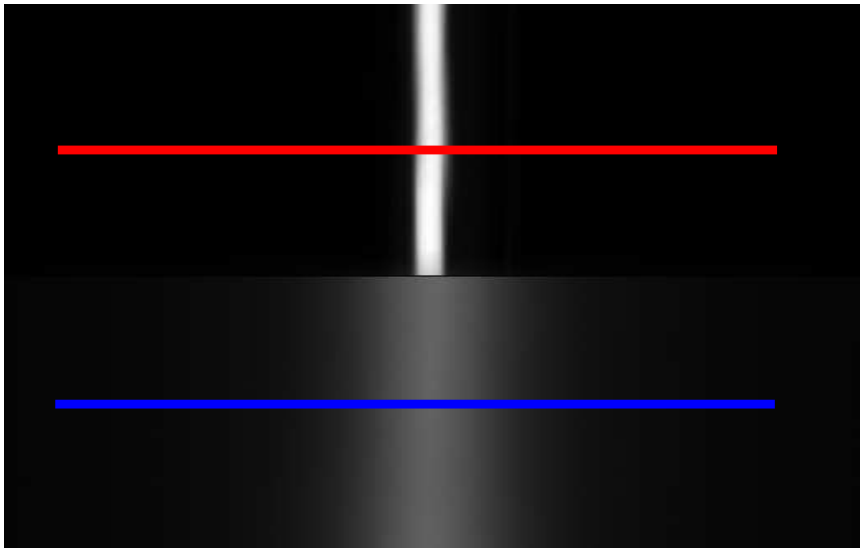
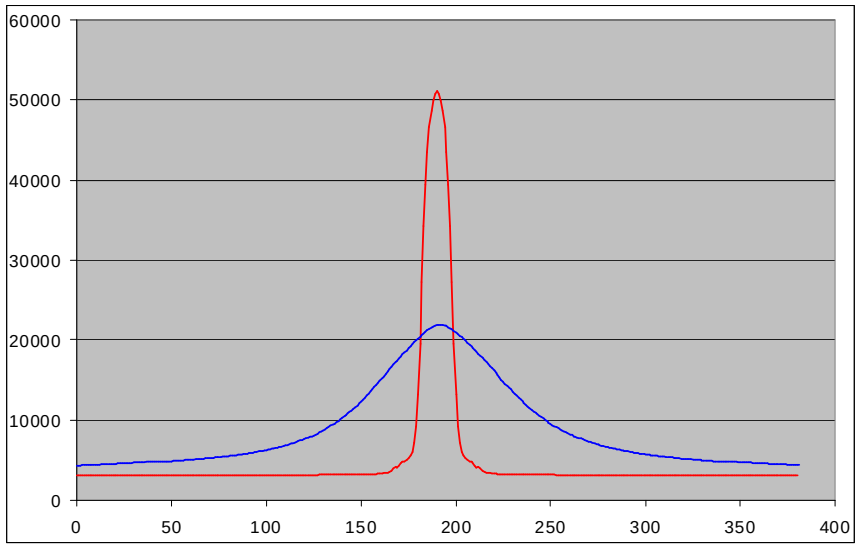
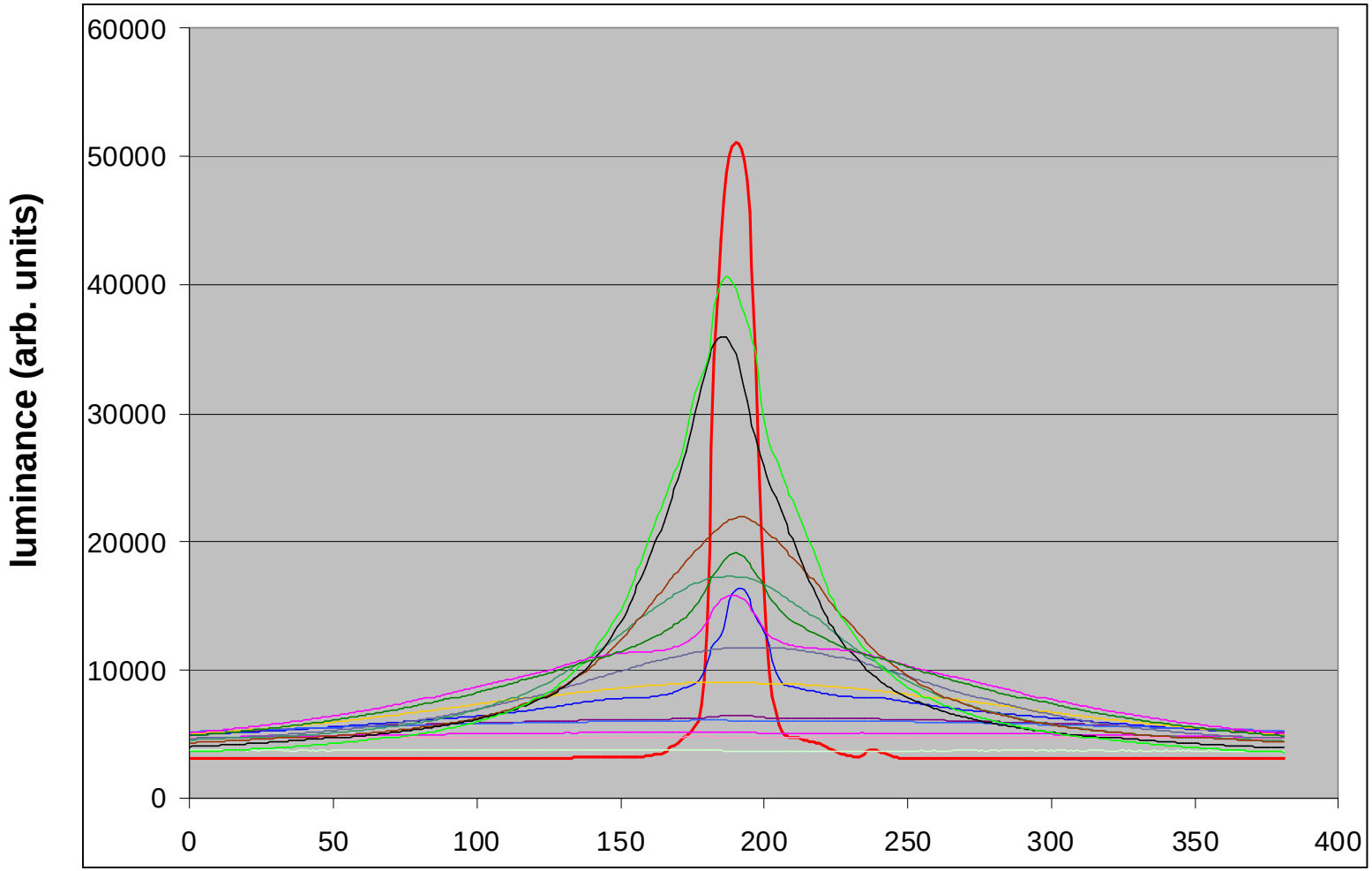


Image of linear light source reflected in the bare glossy LCD-screen (top) and in an AG-layer (bottom).



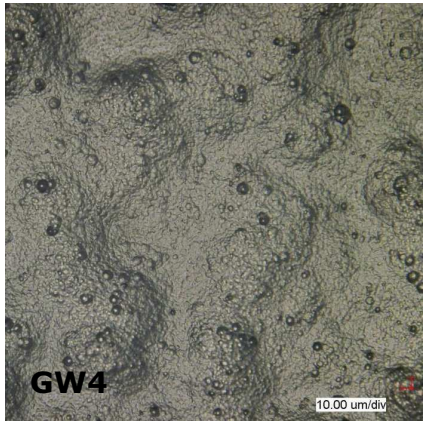
Profile of light intensity reflected by the bare LCD-screen (red) and by the scattering AG-layer (blue).

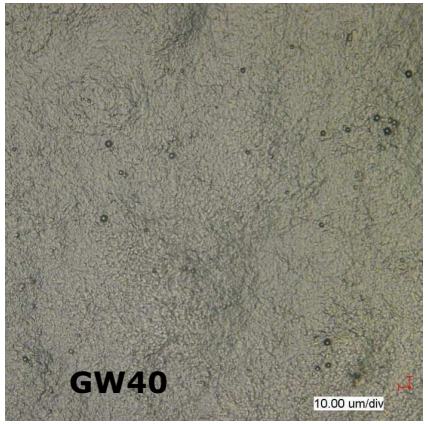
Scattering Characteristics of 14 AG-Glasses

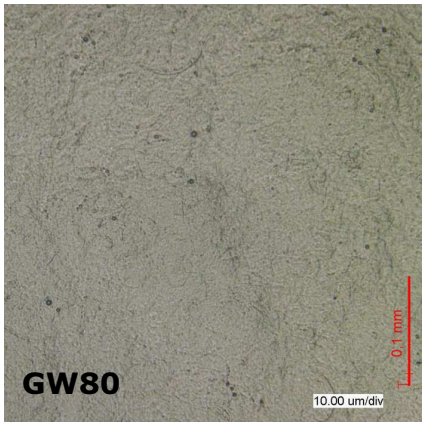


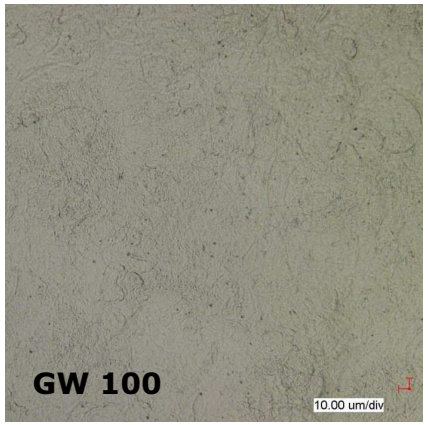
Directional variations of the intensity of light reflected from the AG-layers used for sparkle evaluation in this article.

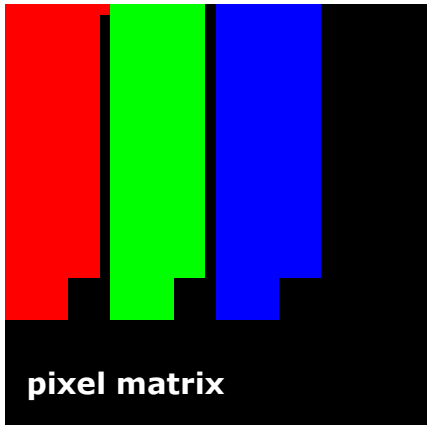
Surface Topographies of AG-Glasses

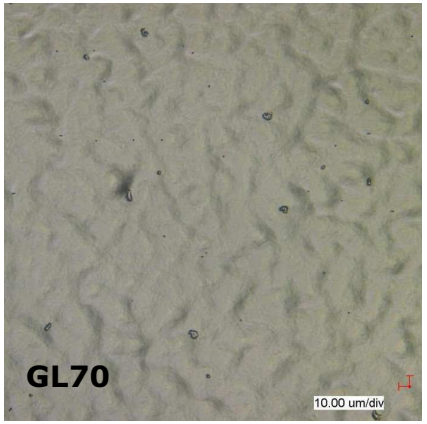


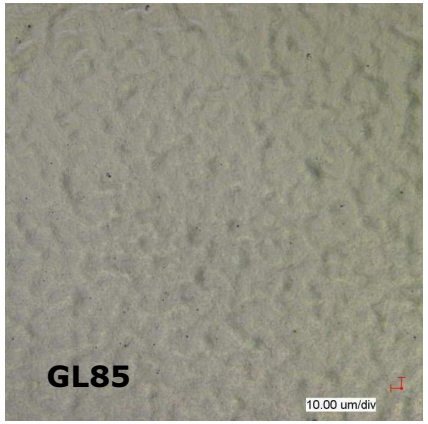


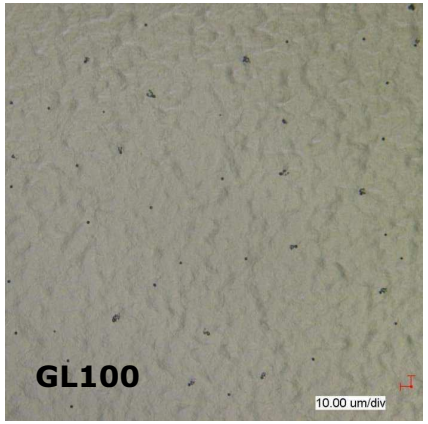












Micrographs by courtesy of

Dr. Axel Reich,
Karsten Schaude
Berliner Glas
Surface Technology
Herbert Kubatz
GmbH&Co. KG

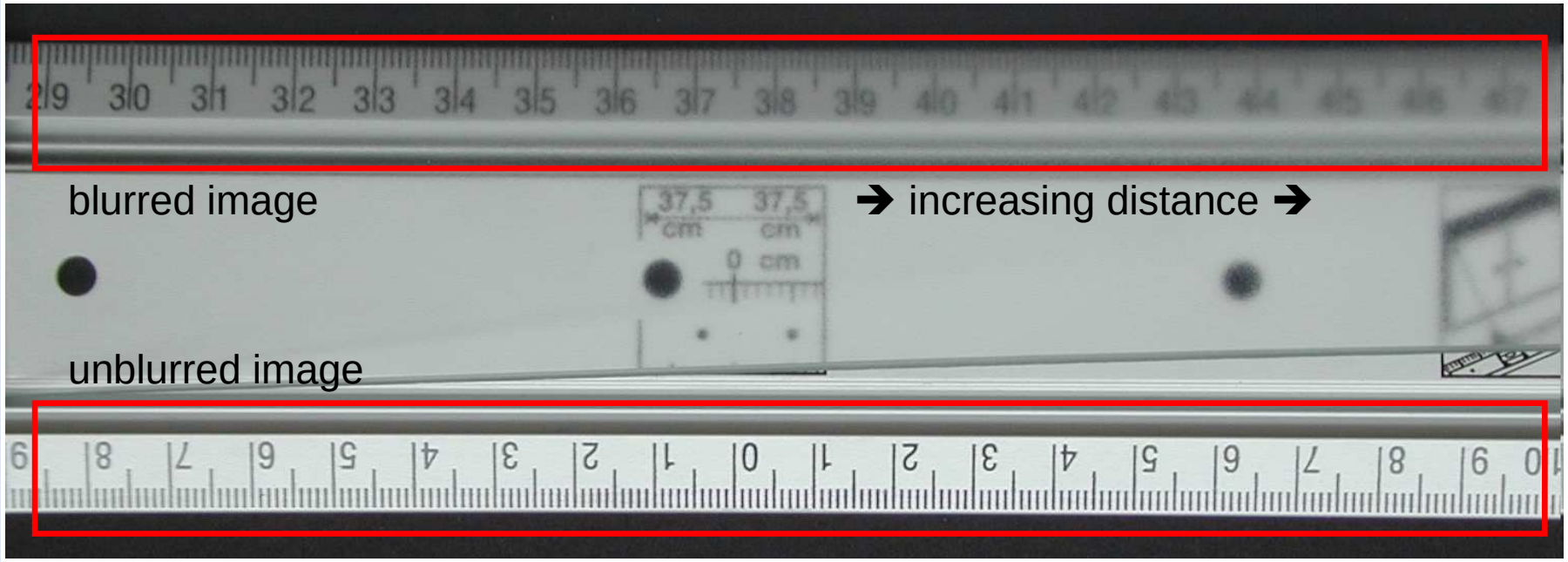
Distinctness of Image

Distinctness of image, DOI: deviation of the direction of light propagation from the regular direction by scattering (in the range ± 0,3°).

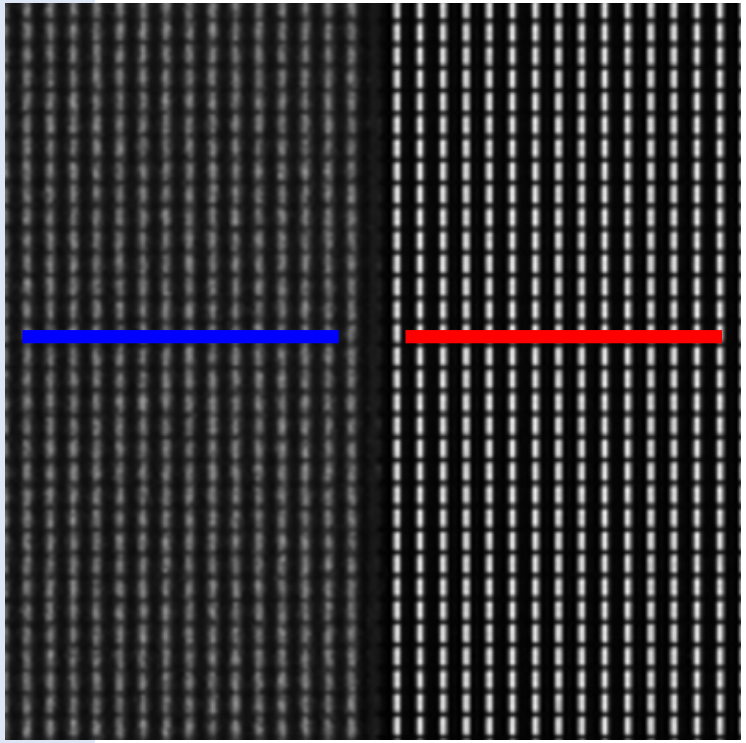
- DOI is sensitive to even subtle scattering effects.
- DOI is measured to characterize the appearance of e.g. polished high-gloss surfaces such as automotive car finishes, mirrors.

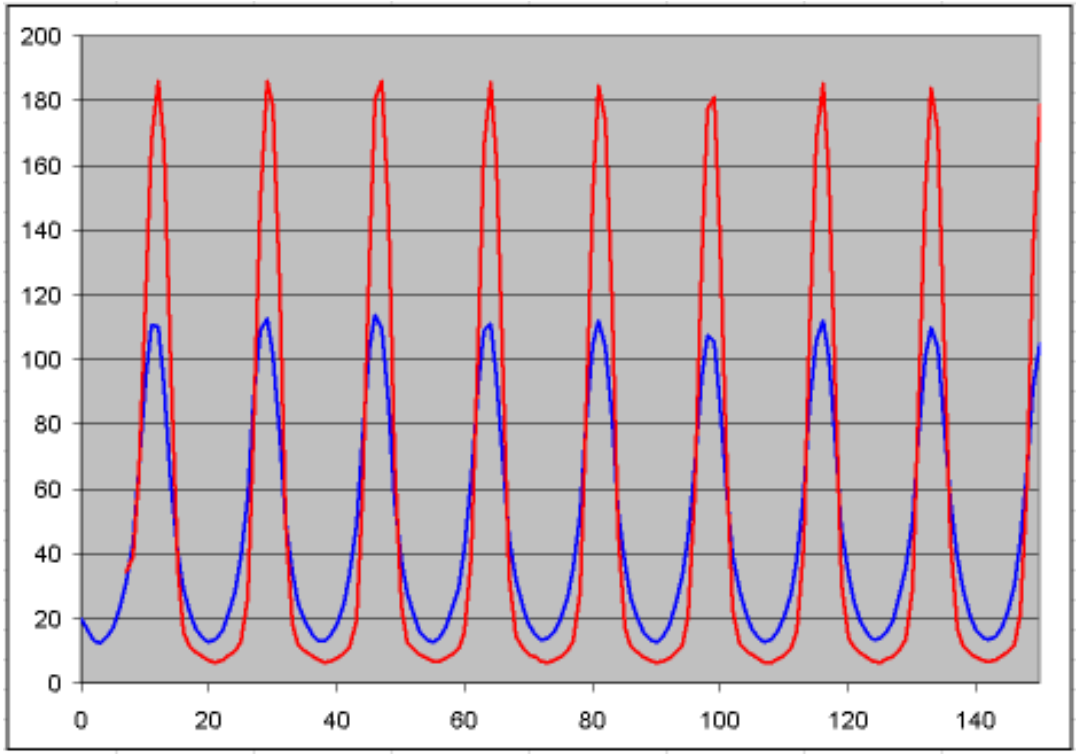
The scattering of the AG-layer effects a low-pass filtering (blurring).

$$MTF = \frac{Modulation \quad with\ AG}{Modulation \quad without\ AG}$$



Distinctness of Image





Intensity modulations obtained from the figure to the left.
Red: without AG-layer, blue: with AG-layer.

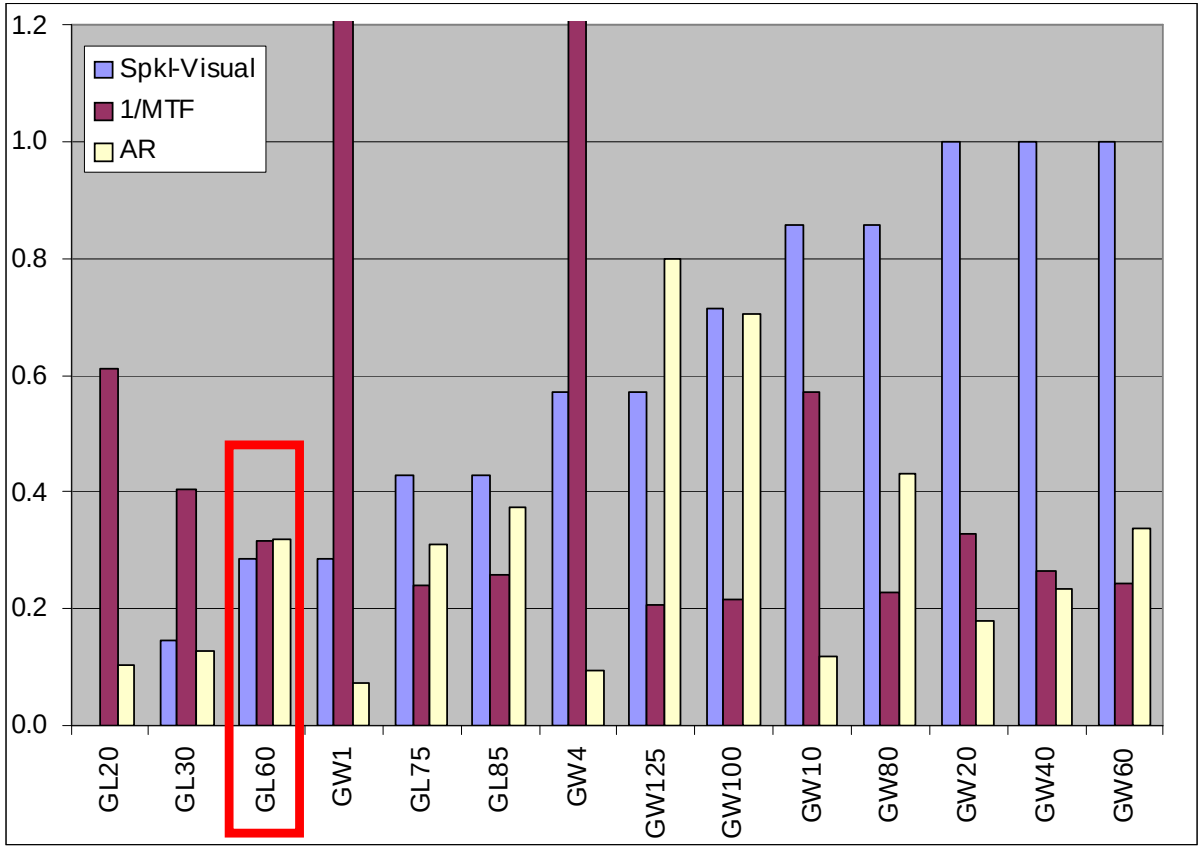
The scattering AG-layer reduces the amplitude and attenuates high-frequency components (smoothing).

$$MTF = \frac{Modulation \quad with\ AG}{Modulation \quad without\ AG}$$

Summary of Results

AG-layer	spkl-vis	MTF	AR
GL20	0.0000	0.3088	0.10182
GL30	0.1429	0.4708	0.12581
GL60	0.2857	0.6015	0.31639
GW1	0.2857	0.0189	0.07240
GL75	0.4286	0.7853	0.30988
GL85	0.4286	0.7323	0.37418
GW4	0.5714	0.1303	0.09463
GW125	0.5714	0.9143	0.79860
GW100	0.7143	0.8766	0.70589
GW10	0.8571	0.3312	0.11907
GW80	0.8571	0.8384	0.43105
GW20	1.0000	0.5733	0.17802
GW40	1.0000	0.7124	0.23099
GW60	1.0000	0.7775	0.33958

Visual rating of sparkle (spkl-vis), reduction of distinctness of image (MTF) and reduction of unwanted reflections (AR) for 14 AG-treated sheets of glass.



Requirements:

- reduction of reflections from ambient light-sources ➔ low AR-value,
- reduction of sparkling effects ➔ low sparkle-value,
- maintenance of image quality of the display screen ➔ high MTF-value.

The properties of AG-layers are not naturally related to each other as required for optimum visual display performance.

Impact

The proposed method for optical characterization of the sparkle of scattering AG-layers can be used by **manufacturers of such coatings** for optimization of their products, since the suppression of unwanted reflections and the undesirable reduction of distinctness of image are obtained at the same time.

Manufacturers of electronic equipment that are combining visual displays with touch sensitive input devices can characterize their products for obtaining suitable results concerning suppression of reflections and maintaining distinctness of image.

This metrology method can be a basis for objective rating of the optical properties and thus for unambiguous communication between customer and supplier.

Sparkle measurement setup available from
Display-Metrology&Systems, Karlsruhe, Germany.