－論文－

● Development of Light-Diffusive UV-Curable Resins for a Novel Thin Backlight System

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LCDバックライトは、反射板、導光板、拡散板、プリズムシート等多くの部材を必要とするために、LCD全体に占める厚さ、重さ、コストの割合が大きい。また、バックライト構成部材界面での反射や部材による光の吸収などにより光の取り出し効率が低下するという問題がある。

筆者らは、次世代モバイル用表示材料技術研究組合(Technology Research Association for Advanced Display Materials, 通称TRADIM)にて株式会社クラレと共同で、1)薄型化および軽量化、2)光取り出し効率の向上、3)アセンブリの簡略化を達成するために、複数の光学フィルムの機能を一枚のフィルムに集約したバックライトの開発に取り組んだ。光学フィルムは、高輝度で白色の散乱光を出射する必要があるが、波長依存性があるため、白色光は得られにくい。筆者らは、Mie散乱理論に着目し、マトリックスであるUV硬化樹脂と光拡散材との屈折率差、光拡散材の粒径を最適化することにより、散乱光を白色光に近づけることができた。さらに、UV硬化樹脂に求められる、速硬化性、低粘度、支持フィルム密着性、金型離型性といったプロセス特性を満足する設計手法を確立し、UVX-5113を開発した。

UVX-5113の連続塗工試験により光学フィルムを作製し、バックライトを試作した。得られたバックライトの厚さは従来品の1/3以下の0.26mmであり、光学特性も良好であった。

1　緒　言

1. Introduction

LCD is widely utilized for the information terminals such as cellular phones, personal digital assistants. As for these applications, LCD should be thin, light, flexible and hard to break for convenience.

But conventional LCD backlight systems considerably occupy in terms of weight and thickness in LCD, and generally flexibility is not enough, because they are essentially composed of a light guide plate, a reflector, a diffuser, and prism sheets (**Fig. 1**).

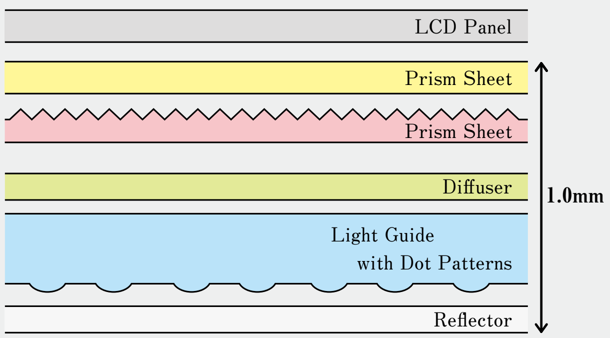

Fig.1　Structure of a coventional backlight system.

In these backlight systems, the light guide plate with the shape of a slab or a wedge has many dot patterns in the rear. Incident lights from the light source such as cold cathode fluorescent lamps and light emitting diode (LED) propagate through the light guide. The propagating lights that reach the dot patterns are diffused through the light guide, and then diffused lights are radiated toward the diffuser. Emanated lights are diffused by the diffusive elements in the diffuser, and they behave as Lambertian.

Additionally, a diffuser has a function that it makes the dot patterns invisible. Orthogonal prism sheets on a diffuser collimate the diffused lights in order to increase the brightness to the direction of viewers effectively.

Conventional backlight systems also have a reflector so as to avoid backward emission of light.

These backlight systems have an advantage that high uniformity of brightness can be easily achieved by arranging the dot patterns appropriately. But they necessarily have disadvantage of lowering efficiency as long as they have to utilize diffusion of light.

Recently, several types of backlight systems with high performance have been proposed to achieve higher brightness, higher quality and higher efficiency [1-5]. In addition to those performances, backlight systems have been demanded to be thinner, lighter, and to simplify assembling.

Some research groups have proposed some novel systems to satisfy these requirements[6-10].

2. OPF Backlight

In a previous paper, we have reported a novel ultra slim backlight system using the optical-patterned film (OPF backlight) that is composed of a single component (**Fig. 2**).

Incident lights from the light source propagate by a total reflection through the light guide. Propagated lights which reach the contact points of the light guide and optical-patterns are picked up toward the optical-patterned film, for those contact points play a role of "optical window".

Picked up lights are reflected at slope of the optical-patterned film, and then, they are radiated toward the LCD panel from OPF backlight. High uniformity of brightness can be achieved by arranging the optical-patterns appropriately[11,12]. The size of a single optical-pattern has been optimized about several tens micrometers.

We are also trying to manufacture OPF backlight system by a roll-to-roll continuous process [13,14], and when our attempt gets success, our new backlight system will be one of the best tools to achieve a thin, light, and flexible LCD with high productivity.

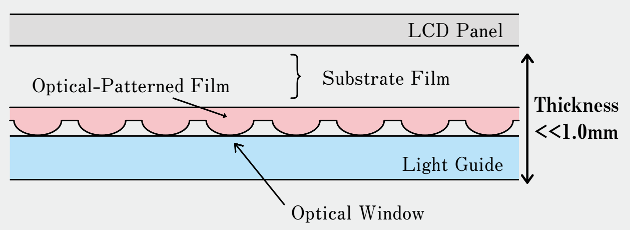

Fig.2 Structure of OPF backlight.

3. UV-curable resins

Most thermoplastic resins are highly viscous and very tough materials to pour into a mold. Especially, a metal mold for producing optical films has very small precise shapes of lens patterns. This means that thermoplastic resins cannot be used for this application without organic diluents. But if organic solvents are used as diluents, they must be dried up during manufacturing process. It takes much time to remove all solvents and makes productivity lower.

Furthermore, the apparatus and energy cost also high.

On the other hand, UV-curable resins are low viscous liquid before cure even without organic solvents, because low molecular weight of acrylic monomers act as reactive diluents. When UV-curable resins are employed as the material for optical-patterned films, drying process is not required.

Moreover, they can cure rapidly when UV is radiated as shown in **Fig. 3**. They have the advantages of low energy costs, space-saving, and high productivity due to their features. UV-curable resins are expected to be the best way to obtain OPF backlight with high productivity by a roll-to-roll continuous process when a UV-radiation system with conveyer is adapted. We will propose new materials and principles for a novel backlight system.

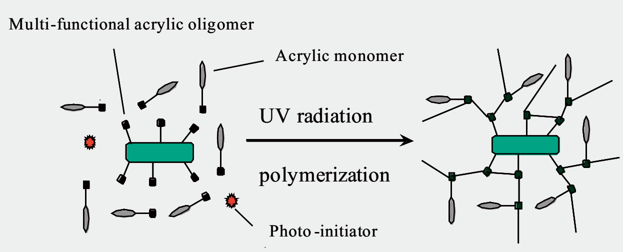

Fig.3 Schematic of UV-curing of acrylates.

4. Light-diffusive particles

The refractive indexes of UV-curable resins should be higher than that of a light guide film in order to obtain high brightness. And the difference of the refractive index between UV-curable resins and light diffusive particles will be required to achieve sufficient light diffusivity. Further, diffused light must be white as a light source of LCDs.

However, it is difficult to pick diffused light up as white light, because scattering intensity and efficiency depend on wavelengths. So the refractive indexes and the diameters of the light-diffusive particles have to be optimized, and light-diffusive particles should be easy to design and control their refractive index and particle size. Viewed in these lights, acrylic polymer particles are expected to be suitable materials, because the refractive indexes can be easily varied by copolymerization of various types of acrylic monomers, methacrylic monomers, and styrene derivatives.

The diameter of the particles can be well-defined from 1 to 10 micrometers by changing conditions of polymerization process. While the dispersibility of light-diffusive particles with UV-curable resins is important in order to produce uniform optical films, most commercially available acrylic particles show a tendency to aggregate or get swollen in UV-curable resins. We have solved this problem by using graft polymerization method of macromonomeric surfactant with monomers. The light diffusive particles we employed showed good dispersibility and tolerance toward various organic solvents. Their trade name is " ARON TM-series".

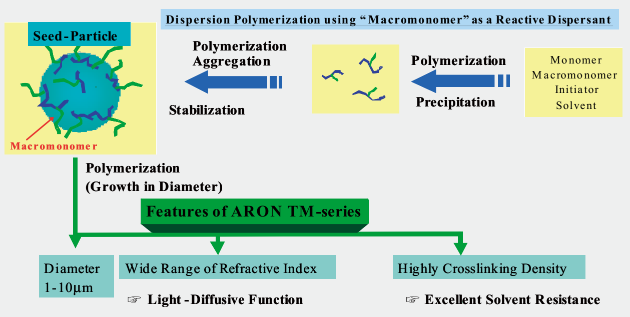

Fig.4 Manufacturing process and features of ARON TM-series.

5. Formulations and optical properties

We prepared UV-curable formulations with various refractive indexes, and then added well-defined polymer particles (**Table 1**). The haze values of UV-cured films were also shown in the same table. These data indicated that the light strongly diffused when the differential refractive indexes between matrix and polymer particles were larger or the diameter of particles was small.

Table 1 Formulations of UV-curable resins with polymer particles.

Run No.	UV-Curable Resins		Polymer Particles		Haze
	n_D^{25} (before cure)	n_D^{25} (cured film)	n_D^{25}	D (μm)	(%)
1	1.5030	1.5330	1.497	2.4	42
2	1.5461	1.5701	1.497	2.4	94
3	1.5552	1.5810	1.497	2.4	97
4	1.5461	1.5701	1.497	3.7	94
5	1.5552	1.5810	1.497	3.7	96
6	1.5461	1.5701	1.497	5.4	91
7	1.5552	1.5810	1.497	5.4	90

* The ratio of UV-resin and polymer particles was 90 to 10 by weight.
*Film thickness of UV-resin was 50μm.

The tint of backlight using these films with high haze value was shown in **Fig. 5**. They were found to be deviated from the center of chromaticity coordinates.

This phenomenon meant that the transmitted light was not white, and other factors existed to control scattering properties of light-diffusive UV-curable resins.

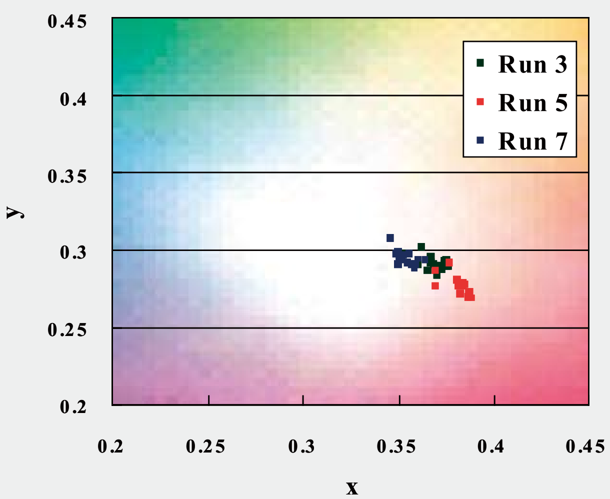

Fig.5 Chromaticity coordinates for backlights using 20μm thickness ofcured films.

Koike *et al*. proposed the backlight system using a highly scattering optical transmission (HSOT) polymer which consisted of the micro particles in the transparent matrix by analyzing Mie scattering theory. In Mie scattering theory, scattering efficiency Q_{sca} depends on the diameter of micro particles D, the differential refractive index between matrix and micro particles Δn, and the wavelength of incident light λ.

Koike *et al*. reported that colorless HSOT backlight system could be achieved by optimizing ρ values that were obtained from D, Δn, and λ, as shown in **Fig. 6**[15].

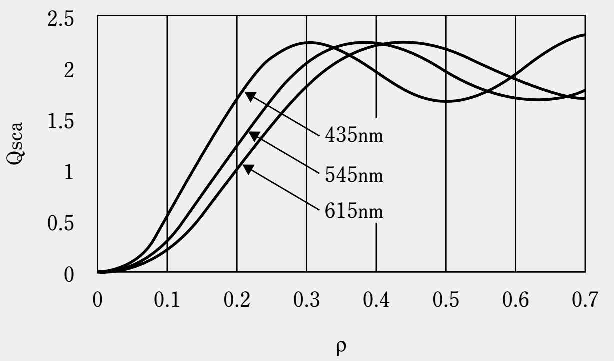

Fig.6 The relation between Qsca and ρ(=△nD).

Then we calculated ρ values of model formulations (**Table 2**) and the dependence of parallel transmittance was shown in **Fig. 7**. They clearly showed the wavelength dependence of parallel transmittance, and the optimized ρ value was determined both theoretically and experimentally.

Table 2 Formulations of UV-curable resins with polymer particles.

Run No.	UV-Curable Resins		Polymer Particles		Haze
	n_D^{25} (before cure)	n_D^{25} (cured film)	n_D^{25}	D (μm)	(%)
7	1.5552	1.5810	5.4	0.45	90
8	1.5373	1.5608	5.4	0.34	90
9	1.5382	1.5681	5.4	0.38	91
10	1.5614	1.5898	5.4	0.50	88
11	1.5754	1.6122	5.4	0.62	79

*The ratio of UV-curable resin and polymer particles was 90 to 10 by weight.
*Film thickness of UV-curable resin was 50μm.
*Run7 was the same sample as in Table1.

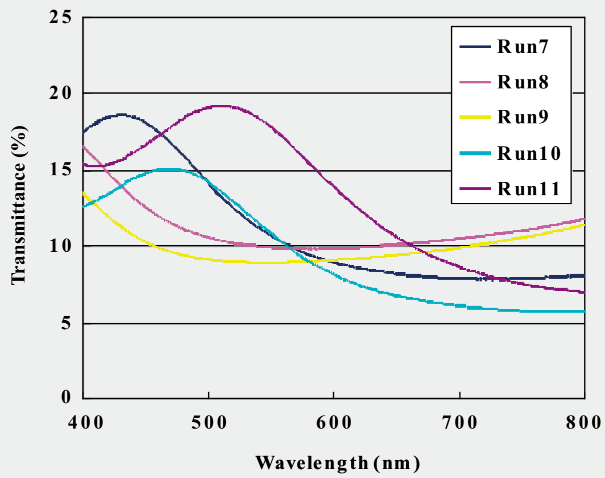

Fig.7 Parallel transmittance of light-diffusive UV-cured films.

The tint of backlights using them was shown in **Fig. 8**, and colorless transmittance was found to be obtained when ρ value was around 0.35.

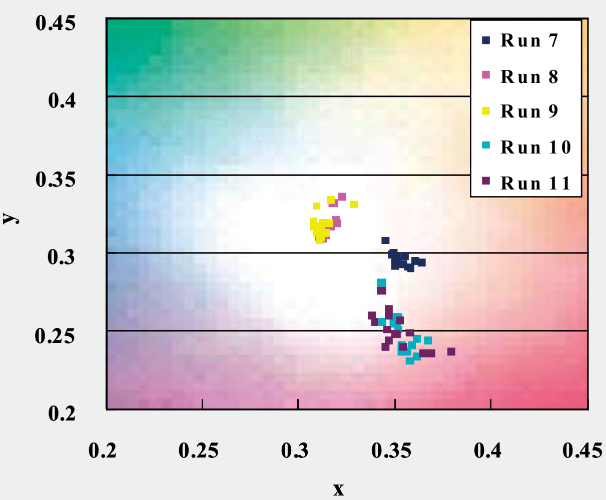

Fig.8 Chromaticity coordinates for backlights using 20μm thickness of cured films.

The scattering behavior of the cured films was evaluated by a goniophotometer. **Fig. 9** shows the relation between scattering angles and relative light intensity at three different wavelengths, which correspond to red, green, and blue. The uniformity of relative light intensity on each wavelength was relatively good, when ρ value was 0.35. On the contrary, the scattering angle on 438nm and 558nm was obviously narrower than that on 680nm, and the uniformity was not sufficient, when ρ value was 0.62.

In this case, the transmitted light will get reddish, when a viewer watches the display diagonally.

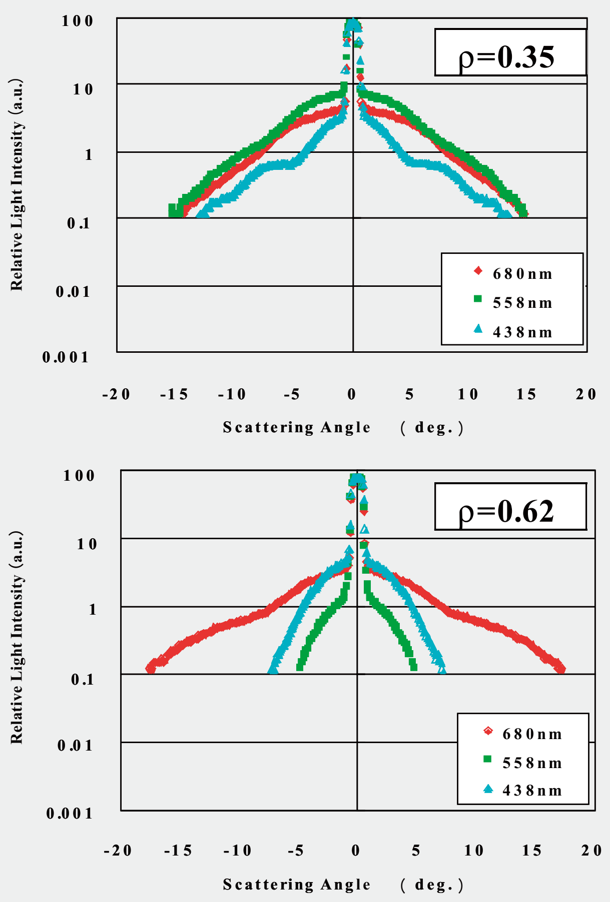

Fig.9 The relation between scattering angles and relative light intensity.

A roll-to-roll continuous process is expected to be one of the best methods to manufacture optical-patterned films in high productivity.

And UV-curable resins are good solutions for this purpose due to their excellent features, such as rapid cure, space-saving, low viscosity, organic solvent-free, and so on (**Fig. 10**).

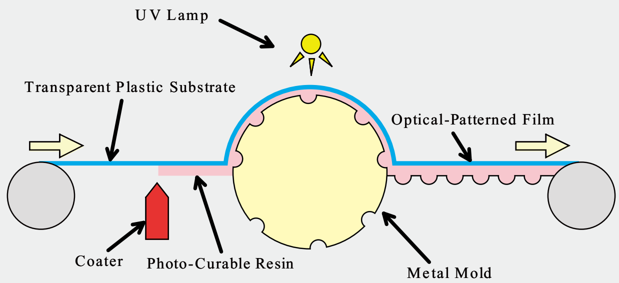

Fig.10 A roll-to-roll continuous process for manufacturing the optical-patterned film.

In addition to optimization of optical properties, UV-curable resins must show industrially sufficient curing rate, good removability from a metal mold, and good adhesion to a substrate film to establish a highly productive reliable process. We have established the design principles to obtain the formulations which good removability from a mold and adhesion to a film can be compatible by adjusting curing rate and crosslinking reactions.

Major properties of the optimized formulation were shown in **Table 3**.

Table 3 Major properties of the optimized formulation

Trade Name	UVX-5113
Viscosity (mPa･s at 25°C)	33
n_D^{25} (before cure)	1.512
n_D^{25} (cured film)	1.550
Diameter of particles (μm)	5.4

The appearance of the obtained optical patterned film by a roll-to-roll process, the microscopic photograph of the lens patterns, and its cross section were shown in **Photo.1**. UVX-5113 proved to show excellent adhesion to the substrate film and the remobalility from the metal mold.

Furthermore, the cross section showed that ARON TM-series possessed excellent tolerance toward UV-curable resins, and they dispersed uniformly in the formulation[16].

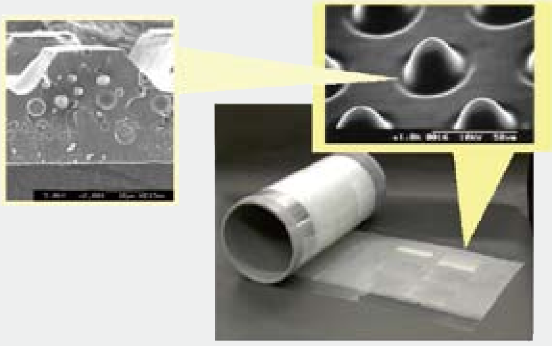

Photo. 1 The obtained optical patterned film.

Finally, we showed the assembled OPF backlight in **photo. 2**. We turned on LEDs to lighten the bent backlight, and found out that it could radiate uniformly even with a bent shape unlike a conventional backlight system. The total thickness of the obtained OPF backlight was 0.26mm, and we have succeeded in achieving the thinnest backlight in the world[17].

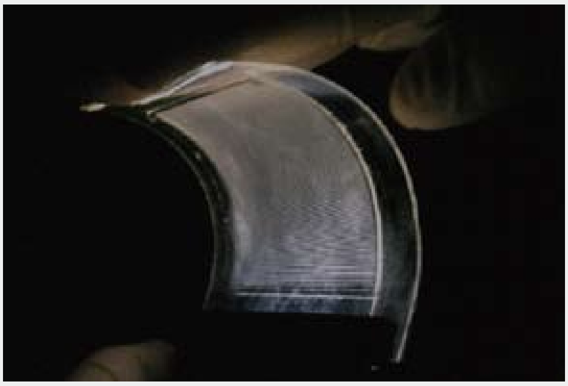

Photo. 2 Appearance of the lightened "bendable" OPF backlight.

6. Conclusions

We have developed light-diffusive UV-curable resins with well-controlled scattering property by adjusting the diameter of light-diffusive particles and the differential refractive index between UV-curable resin matrix and the particles. Optical-patterns could be formed accurately using the formulations due to their low viscosity, and the polymer particles showed good dispersibility and tolerance toward UV-curable resins. Additionally, they showed good removability from a metal mold and good adhesion to a substrate film. UV-curable resins have an advantage of high productivity due to their features such as rapid cure, space-saving, and organic solvent-free. We expect that our UV-curable formulations can provide optical-patterned films for a novel slim backlight system by a roll-to-roll continuous process with high productivity.

7. References

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