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SELENIUM PHOTOCONDUCTORS FOR ELECTROPHOTOGRAPHY

Yasuo Nakaura
Mikio Takeuchi
Tatsuo Tanaka

1 FOREWORD

A photoreceptive selenium drum was used in the first Xerox copying machine in 1950. Since then, selenium drums have been used in many electrophotographic processing units. Their use is increasing, together with the use of such photo sensitive materials as zinc oxide (ZnO), cadmium sulfide (CdS), and organic compounds (OPC), as listed in *Table 1*.

Fuji Electric selenium drums have two outstanding characteristics:

- High sensitivity with excellent spectral response
- Excellent durability with long service life

However, the drums are sensitive to temperature and physically delicate, so they-must be handled carefully. Nevertheless, they play the major role in electrophotographic processing.

Selenium drums can be roughly divided into the following types:

- Pure selenium drum
- Selenium-tellurium drum
- Selenium-arsenic drum

Fuji Electric has spared nothing in developing and improving photoreceptive drums, obtaining excellent results in photosensitivity, image retention, and spectral response. Now the selenium drum most suitable for a particular user can be selected from several, which are listed in *Table 2*. and production flowchart is shown in *Fig. 1*.

Fig. 1 Fuji Electrics' selenium photoconductor drums.

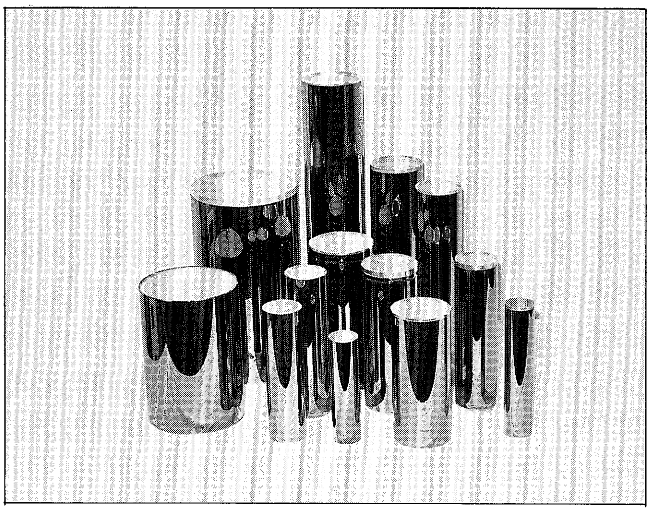


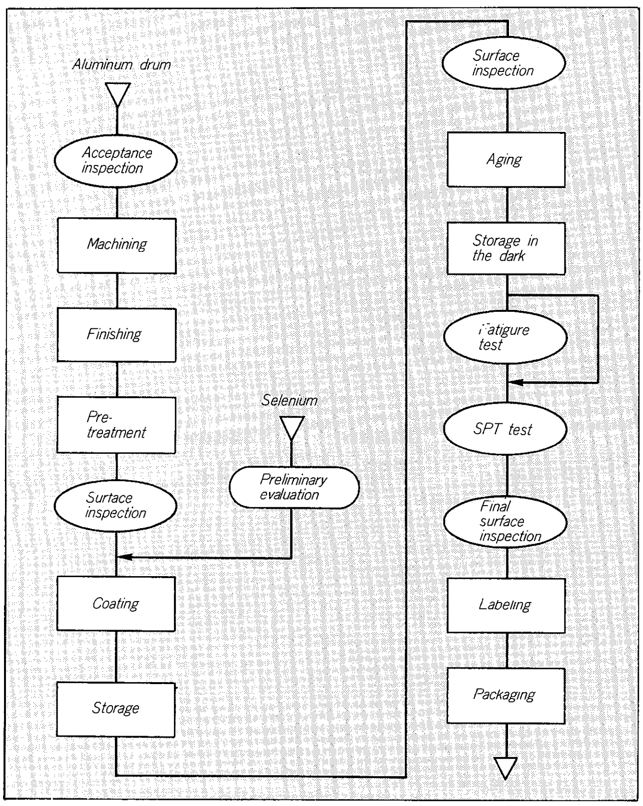
Table 1 Photoreceptive drums and their characteristics

Material	Filming method	Configuration	Carrier	Filmthickness	Features
Amorphous calcogenide • a-Se • a-As_2Se_3 • a-Se-As-Te	Vacuum coating (Drum)	Single layer, multiple layers	Positive holes	70 μ or less	High sensitivity Excellent durability
Microcrystal resin dispersion • ZnO (coloring matter)-resin • CdS-resin	Mixing dispersion Coating Drying (sintering)	Single layer, multiple layers	Electrons	20 μ or less 30 μ or less	Complex process Non-uniform quality and difficult quality control
Organic Photo-conductive materials • PVK-TNF • Organic materials: CTL Organic dyes: CGL	(Drum or sheet)	Multiple layers, function separation	Positive holes, electrons	10 to 15 μ	Poor stability and durability Low price

Table 2 Basic series of photoreceptive selenium drums

Type	Layer Structure	Spectral Sensitivity	Features: Advantages	Features: Disadvantages
4c	Se-Te Se-Te Substrate		High sensitivity Low fatigue Wide spectral response long service life	Slightly difficult manufacturing process
4d	Se-As Se-Te Se Substrate		Super-high sensitivity High long-wave length sensitivity	Difficult manufacturing Fairly temperature-dependent
5	Se-As Substrate		High sensitivity High heat resistance High surface solidity	Fairly temperature-dependent

Fig. 2 Production flowchart

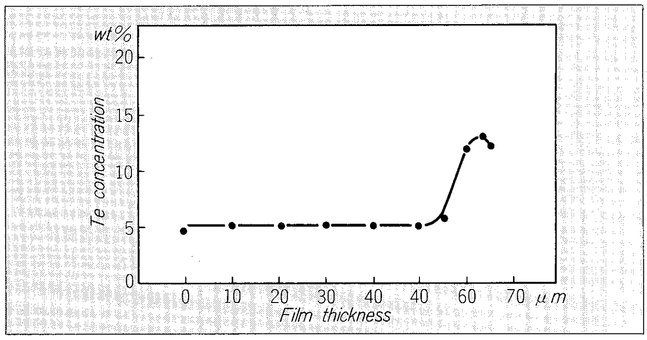


2 PHOTOCONDUCTIVE SELENIUM DRUM TYPE 4C

2.1 Layered structure

Photoconductive selenium drums of type 4c have the basic layered structure shown in the figure below. The CGL and CTL layers have separate functions. The CGL layer generates optical carriers, and the CTL layer transfers the carriers to the aluminum substrate and also accepts and reserves charges in the dark. The values meet the standards for Fuji Electric's photoconductive selenium drum type 4c.

Fig. 3 Te concentration distribution in type 4c drum



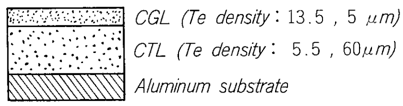


Fig. 3 shows the Te density distribution by EPMA.

2.2 Main features

(Advantages)

(1) Very sensitive compared to other photoconductive materials (ZnO, CdS, and OPC)
(2) Stable temperature characteristics
(3) Low fatigue
(4) Long service life

2.3 Light sensitivity

In general, when light strikes the surface of a photoconductive drum, the surface potential decreases in proportion to the exposure. This is shown by the light decay curve. The sensitivity of a photoconductive drum is defined by the exposure intensity necessary to decrease the initial surface potential to half. The intensity is called the "half-

Fig. 4 Te concentration and sensitivity

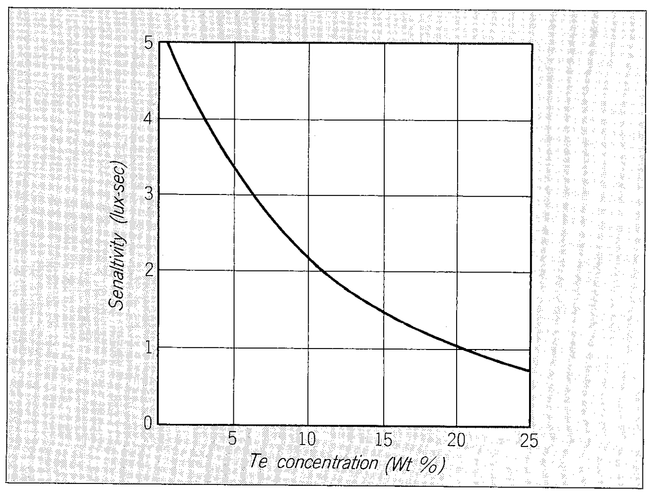
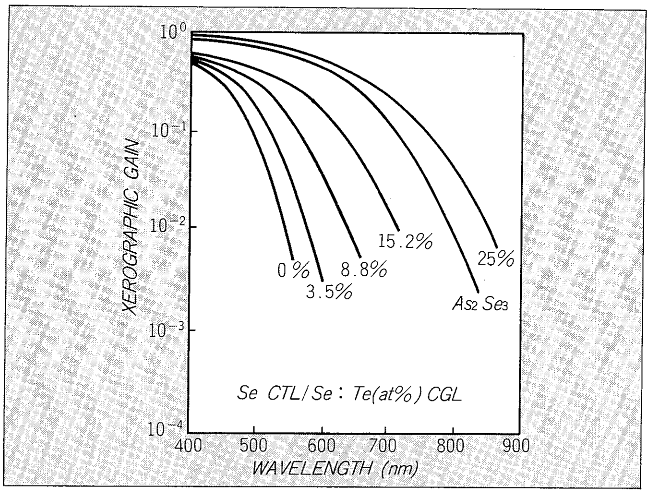


Fig. 5 Spectral sensitivity



decay exposure" and is measured in units of lux-sec.

The sensitivity of Se-Te photoconductive drum type 4c depends on the Te concentration of CGL, as shown in *Fig. 4*. *Fig. 5* shows the general spectral sensitivity of the type 4c drum (at 10 V/μm).

Photoconductive selenium drums of type 4c are used in low-and medium-speed copiers, and their sensitivity is in the range of 2 to 4.5 lux-sec. using a halogen light source with a 2000 K color temperature. (This is 1.2 to 2.3 lux-sec. for a light source with a 2850 K color temperature.)

As you can see from *Fig. 4* the sensitivity of the drum can be improved by increasing the Te concentration in the CGL. However, there are limitations due to the fatigue and temperature characteristics.

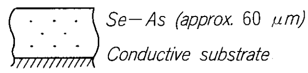
2.4 Type 4C photoconductive drum outline

Item		Characteristic value
Size	Shape (standard)	Outside drum diameter: ϕ80, ϕ90, or ϕ120mm
Configuration	Substrate material	JIS A3003TDS Aluminum alloy drawtube
	Photoconductive layer	Se, Te
	Film thickness:	65±5 μm
	Adhesion strength:	Stronger than 24 mm Nichiban adhesive tape
Potential characteristics	Charging characteristics	——— ±10% = I_{AL} (Test in a copier)
		Deflection for one drum: 100V or less
	Sensitivity characteristics	EDA measurement (half-decay exposure) 2 to 4 lux-sec (T=2000 K)
		Conversion to SPT measurement ($V_1 - V_2$)
		Deflection for one drum: 80V or less
	Residual potential: 60V or less	
Environmental characteristics	No serious trouble will arise in the following environments	
	Storage at high temperature	45°C, 1000 hours
	Temperature and humidity cycle	35°C, 60%, 9 hours 25°C, 85%, 15 hours Repeated for 1000 hours
	Heat cycle	−20°C, 1 hour Room temperature, 30 minutes 40°C, 1 hour Room temperature, 30 minutes Repeated 5 times
	Storage at low temperature	−20°C 1000 hours

3 PHOTOCONDUCTIVE SELENIUM DRUM TYPE

3.1 Layered structure and main features

(1) Layered structure



(2) Se-As profile of photoconductive drum type See *Fig. 6* for the results of EPMA measurement.

(3) Main features of photoconductive drum type

1) High sensitivity

Fig. 6 Se-As profile by EPMA

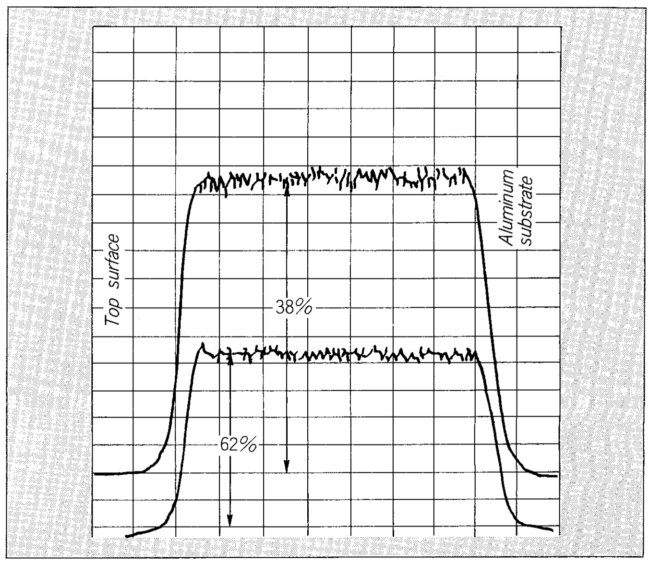
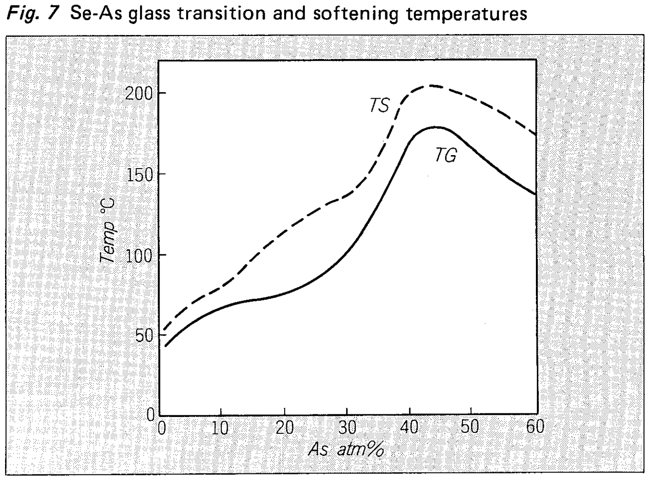


Fig. 7 Se-As glass transition and softening temperatures



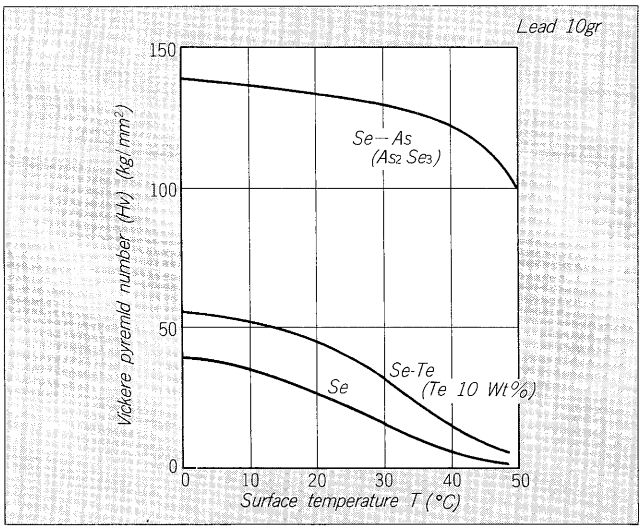


Fig. 8 Surface hardness of photoconductive selenium drum

Half-decay exposure by 2850 K halogen lamp Approx. 0.5±0.1 lux-sec.

2) High heat resistance
Withstanding 55°C for 1000 hours or more. *Fig. 7* shows the transition and softening temperatures of Se-As glass.

3) High surface hardness
H_V = 130 kg/mm² (25°C)
Fig. 8. shows the surface hardness of a photoconductive selenium drum.

3.2 Charge acceptance

Charge acceptance depends on dielectric constant of material and a thcikness of the photoconductive drum. As to type 5 having one layer of As_2 Se_3, which is stable, the dieledtric constant is settled. So charge acceptance depends on the thickness.

Table 3 Dielectric constant of photoconductive selenium drum

	Dielectric constant	Thickness	Charge acceptance
Se/Te	~7	~60 μm	1
As_2 Se_3	~11	~60 μm	~½

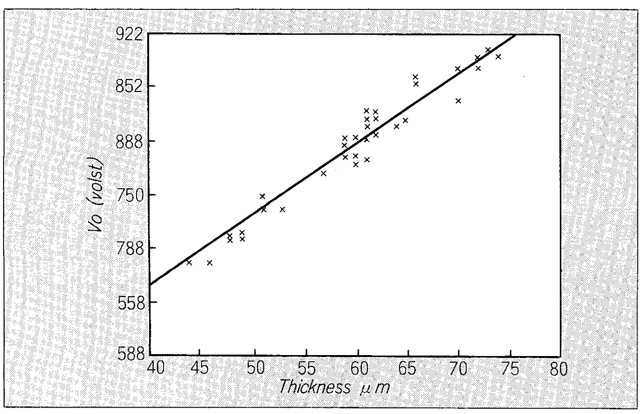
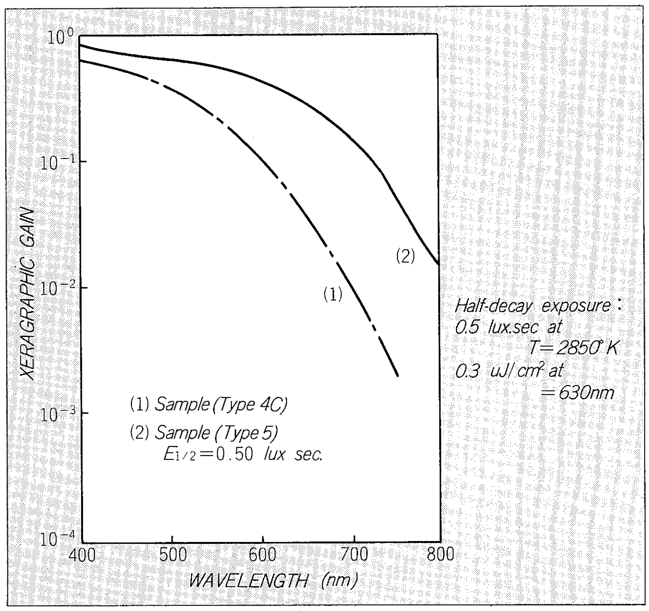


Fig. 9 Correlation of thickness and charge acceptance

The correlation of the thickness and the charge acceptance is shown in *Fig. 9*.

Comparing charge acceptance between Se/Te photoconductive drum and As_2 Se_3 one, the latter is lower and needs consideration on design of charging process.

Fig. 10 Spectral sensitivity



3.3 Type 5 photoconductive drum outline

Item		Characteristic value
Size	Shape and size	Outside drum diameter: φ80, 120, 242, 262mm (printer) φ80, 90, 100, 120mm (PPC)
Structure	Substrate	JIS A3003TDS Aluminum alloy drawpipe
	Photoconductive layer	As2Se3 One layer
	Film thickness:	60 ±5 μm (standard value± 10%)
	Adhesion strength:	Stronger than 24-mm Nichiban adhesive tape
	Surface hardness:	130 kg/mm² ≤ under Hv10 (10g micro-Vickers hardness load) at 20°C
Potential characteristics	Charge acceptance	___V ±10% (Potential depends on the charging conditions)
	Sensitivity characteristics (at 22°C)	
	Half-decay exposure (000V → 400V)	0.3 ±20% (μJ/cm²)(at 630 nm) 0.5 ±20% (lux-sec)(T=2850 K)
	Residual potential (000V →)	100V or less (at 630 nm. 1.5μJ/cm²) or (T=2850 K, 2 lux-sec.)
	Repetition characteristics specified for each unit	
Environmental characteristics	No serious trouble must arise under the following environmental conditions.	
	Storage at high temperature	55°C, 1000 hours
	Temperature and humidity	40°C, RH80%, 1000 hours
	Storage at low temperature	–20°C, 1000 hours
	Storage life	30°C, RH65% or less, 18 months

3.4 Photosensitivity

Since As_2Se_3 is stable, the photosensitivity is stable, too. Its spectral sensitiviey covers long wavelength regents and has high sensitiviey because of narrow band width. The comparison of photosensitivity between Se/Te photoconductive drum and As_2Se_3 one is shown in *Fig. 10*.

4 PHOTOCONDUCTIVE SELENIUM DRUM TYPE 4D

4.1 Layered structure

Fig. 11 shows the basic layered structure of a type 4 D photoconductive drum. The aluminum substrate is covered with a carrier transport layer (CTL) on the outside. The basic layered structure consists of CTL (=60 μm), CGL (=0.8 μm), and OCL (2 μm) although, strictly speaking, there are five layers. *Fig. 12* shows how the zerographic gain is affected by the wavelength. As you can see, there are two peaks separated at $\lambda = 580$ nm; these are probably due to the atructure. Carriers are generated in different layers according to the wavelength of the incident photon.

Fig. 11 layered structure

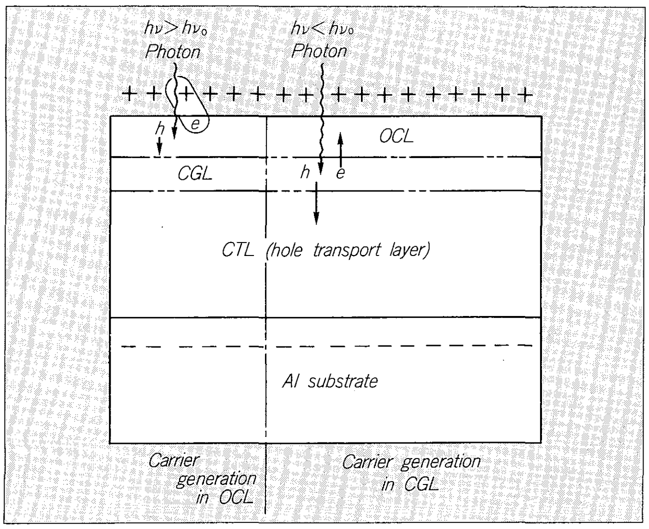
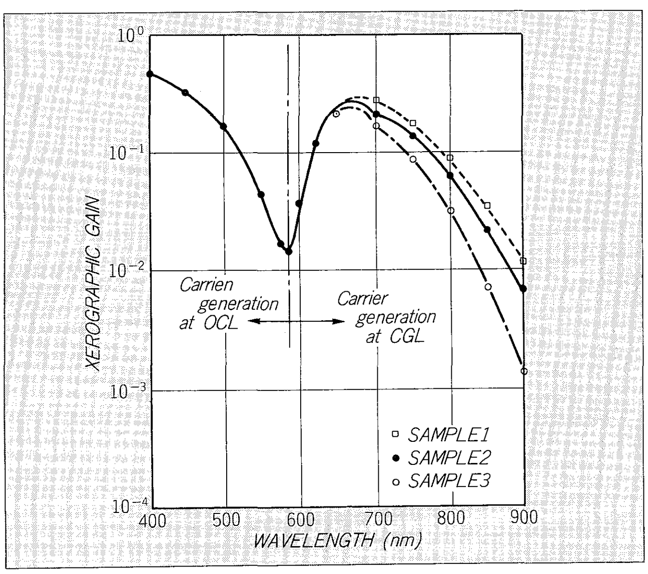


Fig. 12 Spectral sensitivity



4.2 Operating mode

1) Short-wavelength mode

At $\lambda < 580$ nm, incident photons are absorbed by the OCL and carriers are generated near its surface. Among them, electrons are combined with the positive holes caugth in deep traps of the surface by corona discharge. The remaining positive holes pass through OCL, CGL, and CTL and reach the aluminum substrate. *Fig. 12* shows the spectral characteristics for short-wavelength light, which are the same as those of OCL only.

2) Long-wave mode

If incident photons of $\lambda > 580$ nm are received, carriers are generated in CGL. At $\lambda < 650$ nm, photons are partly absorbed by OCL, so generated carriers are recombined

4.3 Type 4D photoconductive drum outline

	Item		Characteristic value
Dimensions	Shape and dimensions		Outside drum diameter: φ120mm Effective printing width: 300mm, max.
Structure	Substrate		JIS A3003TDS Aluminum alloy drawpipe
	Photo-conductive layer		Se-Te alloy Multiple layers
		Film thickness	62 ± 5 μm
		Adhesion strength	Stronger than 24-mm Nichiban adhesive tape
		Surface hardness	30 or more at Hv100 (micro Vickers hardness at 10g load) (at 20°C)
Potential characteristics	Charge characteristics		___V ±15% (Potential depends on the charging conditions)
		Deflection in one drum	20% or less
	Sensitivity characteristics (at 22°C)	Half-decay exposure (800V → 400V)	0.6 ±50% (μJ/cm² at 770 nm)
			0.7±50% (μJ/cm² at 780 nm)
			1.3 ±50% (μJ/cm² at 800 nm)
			0.35 ±40% (lux-sec, T=2850 K)
Potential characteristics			The deflection for a single drum is 30% or less.
		Residual potential (800V →)	100V or less (at 800 nm, 10 μJ/cm²) or (T=2850° K, 5 lux-sec)
		Repetition characteristics specified for each unit	
Environmental characteristics	No serious trouble must arise under the following environmental conditions.		
	Storage at high temperature		35°C, 1000 hrs.
	Storage at high humidity		30°C, 80%, 1000 hrs. (No condensation)
	Storage at low temperature		−20°C, 1000 hrs.
	Storage life		35°C, RH 65% or less, 12 months

quickly and cannot become free carriers (geminate recombination). The remaining photons passing through create free carriers in OCL. At $\lambda > 650$ nm, most of the photons are absorbed not by OCL but by CGL and carriers are generated. Electron carriers enter OCL from CGL combined with positive holes on the surface, and disappear. The positive holes enter CTL from CGL then reach the aluminum substrate.

5 CONCLUSION

We have introduced the outline of Fuji Electrics' selenium photoconductor drums.

As described above, our photoconductor drums have the favorable characteristics for the electrophotographic equipment such as PPC's (Plain Paper Copiers) and NIP's (Non-Impact Printers), and have been used in the world wide market.

Since it is expected that the market for the electrophotographic equipment will be grown further and the technical trend for them will be more various and complex, it is certain that the technical demands for the photoconductors will increase more and more.

We continue to make more efforts in the development of the various types of photoconductor including selenium, amorphous silicon and organic materials.