# LASER DIODES AND PHOTOGRAPHIC MATERIALS IN GRAPHIC ARTS APPLICATIONS

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The discovery and commercialization of lasers has truly revolutionized many areas of science and technology. Ever since the first practical laser was demonstrated in 1962, industry has been very quick to adapt new lasers for a wide range of applications.

During the last 25 years, thousands of lasers have been discovered; and a few have achieved phenomenal growth. In 1986, total laser sales are expected to reach $600 million. Most of today's applications are in materials processing, optical communications, the military, medicine, and research and development. Graphic arts and reprographics together account for about 8 percent of total laser sales.[1,2]

A rapid transition in the next few years from conventional to a fully electronic prepress system will result in a boost in the application of lasers in the graphic arts industry. This transition will be fuelled by several factors. Chief among them are the growth of cost-effective electronic imaging subsystems and total prepress systems and the rising worldwide demand for printed information.

As a consequence, today a substantial amount of information is either captured or generated and stored digitally. A digital recording system, frequently referred to as an output scanning system, then transforms the stored information into a two-dimensional image on a photographic film, paper, or plate by scanning a focused beam of light across the material. The size of the focused spot of light determines the resolution of the system. The system resolution is measured in terms of the number of resolvable pixels per unit length.

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The light source for a digital recording system must have certain attributes. It must be focusable to a small area, compatible with beam steering and deflecting optics, and reliable. In addition, it must have sufficient and consistent power to record, and it must be long-lasting.

Of all light sources, the laser is uniquely qualified to satisfy all these needs. Lasers are powerful and coherent. They can be focused to less than a micron ($<$0.001 mm) in size and can be deflected over a wide angle.

Traditionally, the graphic arts industry has used gas lasers in prepress equipment. The gas lasers most widely used are Argon Ion, HeCd, and HeNe.

The following section describes the principle of laser operation in very general terms.

## Principle of Laser Operation

In general, atoms can exist in more than one energy level. They have a natural tendency to seek the lowest energy level, called the ground state. However, they can reach higher energy levels by means on collisions or absorption of externally pumped energy, when they are said to reach an excited state. The external pump energy can be in the form of electrical discharge -- chemical, optical, thermal, or current.

In 1917, Einstein recognized that an excited atom can revert to a lower state (which need not be the ground state) through photon emission by means of two distinctive mechanisms, namely:

1) spontaneous emission of energy by the atom (without external influence); and

2) stimulated emission (atom is triggered into emission by the presence of electromagnetic radiation of the proper frequency).

Energy of emission: $$h\nu_{if} = E_i - E_f = \frac{hc}{\lambda}$$ (Equation 1.)

where,

$E_i$ = energy level before emission

$E_f$ = energy level after emission (ground state)

$h\nu_{if}$ = emission energy
$h$ = Planck's constant ($6.625 \times 10^{-34}$) j-s
$\nu_{if}$ = frequency of photon energy
$c$ = speed of light ($2.998 \times 10^{8}$ m/s)
$\lambda$ = wavelength of emission (m)

The mechanism causing stimulated emission is the key to laser operation. The laser medium can be in the form of solid, gas, or liquid, hence the types solid-state, gas, or dye laser. An important feature of lasers is that the emitted photon is in phase with, has the polarization of, and propagates in the same direction as the stimulating wave (laser medium).[3]

When sufficient external energy is pumped into the laser medium, the population of higher energy level atoms (excited state) grow rapidly relative to those at lower energy levels (ground state), eventually resulting in "population inversion." Some of the excited atoms then relax back to a lower energy level, causing a spontaneous emission of photons.

This initial spontaneous emission triggers the induced emission process in the laser cavity. The cavity acts as a laser oscillator wherein the emitted photons are reflected between highly reflective mirrors positioned at both ends of the cavity, causing light amplification. Some form of energy (i.e., electrical, chemical, optical, etc.) would be pumped in to sustain the population inversion. When there is sufficient gain through light amplification, a beam of light is extracted from the active medium.

This process results in laser emission that is coherent and Gaussian in intensity profile.[4]

Although the gas lasers used in graphic arts applications emit enough energy to expose photographic materials, they also impose a number of constraints on the performance of output scanning systems. They are extremely low in power efficiency. They are bulky and expensive. They require external modulation and elaborate optics to form the required spot (this, of course, entails additional costs and a complex design).

The reliability and useful life of these gas lasers are less than desirable and depend on type. HeNe laser is the most reliable and least expensive of those in use today. In general, the laser's lifetime ranges between 4,000 and

10,000 hours. This translates to 1 to 3 years of practical use at a rate of 16 hours/day.

The choice of laser significantly influences the productivity of an output scanning system. Productivity is measured in terms of the recording speed -- i.e., inches/second. Among other factors, the recording speed depends on the following.

1. The intensity of the light beam (ergs/$cm^2$ sec).

2. The velocity of the scanning spot.

3. The scanning density (dots per inch).

4. The photographic sensitivity of the recording material.

The initial cost, operating expense, and reliability of high-powered gas lasers usually restrict the choice of gas lasers to lower powered ones. The velocity of the scanning spot is limited by the power incident on the recording material, the choice of scanning system, and the photographic sensitivity of the recording material.

Limited laser power and short exposure times mandate high speed photographic material. Of course, designing photographic materials with high speed, stability, and high quality is a complex requirement, and such materials can be expensive to produce.

The relationship between the recording speed, photographic speed, scanning density, optical efficiency, and laser power are expressed in Equations 2 and 3.[5] These relationships are also illustrated in Figures 1-3.

Data Rate = $R_x R_y LW/uT$, Hz (Equation 2.)

Laser Power = LWE/eT, watts (Equation 3.)

$R_x$ = fast scan resolution (dpi)
$R_y$ = slow scan resolution (dpi)
L = page length (cm)
W = page width (cm)
u = duty cycle
T = recording speed (secs/page)
E = exposure (ergs/cm )
e = optical efficiency

## LASER POWER, RECORDING SPEED AND PHOTOGRAPHIC SPEED

**Page size: 20" x 25 " Opt. eff: 0.20**

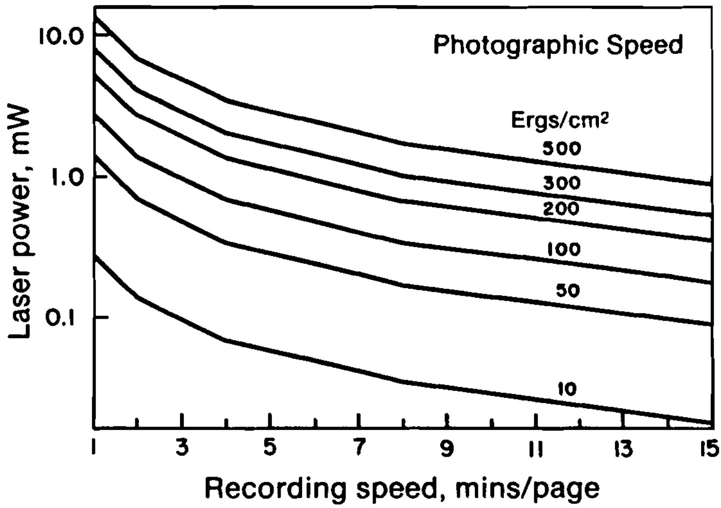


Figure 1.

## LASER POWER, RECORDING SPEED AND OPTICAL EFFICIENCY

**Page size: 20" x 25 " Exp: 50 ergs/sq. cm.**

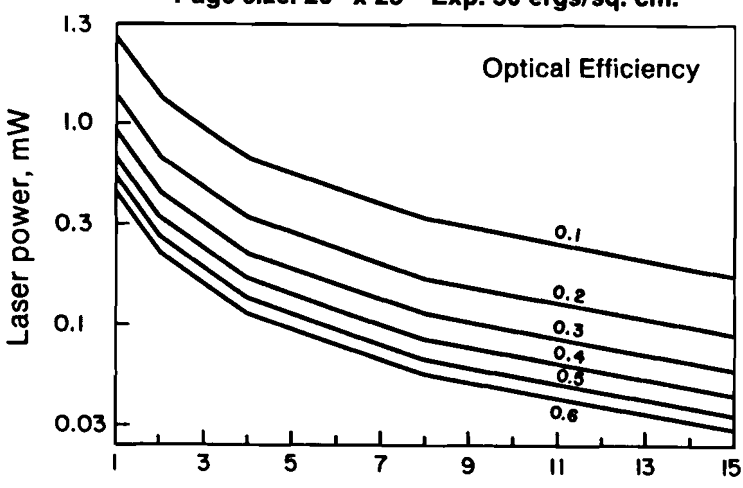


Figure 2.

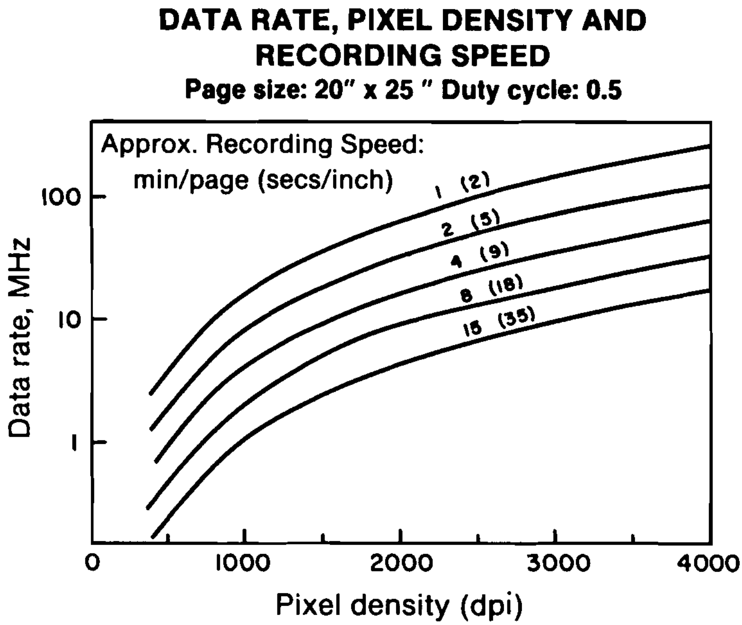


Figure 3.

Although the performance characteristics of gas lasers continue to improve, they are far from the ideal light source. Laser sources with improved performance at lower costs are highly desirable in order to create the high speed and high quality electronic imaging systems of the future.

The search for an improved light source has led to the recent introduction of the semiconductor laser to the graphic arts industry. The relatively tiny laser diode meets all the requirements of a high-speed prepress output system.

Although it has only recently been applied to the graphic arts, semiconductor laser technology is as old as laser technology, itself. The following section discusses semiconductor laser technology in general terms. For a thorough examination of the subject, the reader is referred to other sources where the subject is addressed more rigorously.

## Semiconductor Lasers

The semiconductor is a class of solids with unique electrical properties. The resistivity of semiconductors can be varied by design under precise control. The current carrier concentration in a semiconductor can be intentionally varied by introducing impurity atoms called dopant atoms. They can also be made to conduct with one or two types of current carriers.

The pn junction is a diode made from semiconductor materials. A material is called an n-type semiconductor if most of the charge is carried by the negatively charged electrons (electron flow) and a p-type semiconductor if most of the charge is carried by positively charged holes (hole flow).[6] When a pn junction diode is forward-biased, it resembles an electrical conductor; but when it is reverse-biased, it resembles an insulator -- hence, the term "semiconductor." The semiconductor laser is constructed by sandwiching an active p-type layer between n-type and p-type layers.

The principle of operation of a semiconductor laser is conceptually very similar to that of a gas laser. The lasing medium is the semiconductor, and the pump energy is current.

The possibility of stimulated emission due to recombination of carriers injected across a p-n junction was suggested by Basov in 1961. The first injection lasers were made with the GaAs semiconductor. A considerable amount of development work in the 1960's resulted in lasers with $GaAs/Al_x Ga_{1-x}As$ as heterojunctions capable of operating continuously at room temperature. Of the different types of heterostructure lasers, the double heterostructure (DH) laser is most commonly used today.[7]

When a forward current is applied to the p-n junction, electrons in the n-type region are injected into the active p-type region. The energy bandgap of the active region is narrower than the sandwiching layers. Thus, the injected carriers are confined within the p-type active layer. The differences in the bandgap also result in differences in the index of refraction, so that all emitted light is trapped within the active layer.

When sufficient current is applied, this carrier confinement leads to population inversion (i.e., a state when most of the electron population is in an excited or higher energy state. When these excited electrons relax back to their lower energy or ground state, the energy difference is emitted as photons (Equation 1). This process continues, causing light amplification and subsequent lasing action.

The radiant output from a laser diode depends on the excitation level. As indicated in Figure 4, below the current threshold, the emission is mostly spontaneous and weak, with a broad spectral line-width, and it is incoherent. Above the threshold, the stimulated emission dominates and, therefore, the intensity of the output rises sharply, lasing with a very narrow spectral line width and coherence.[9]

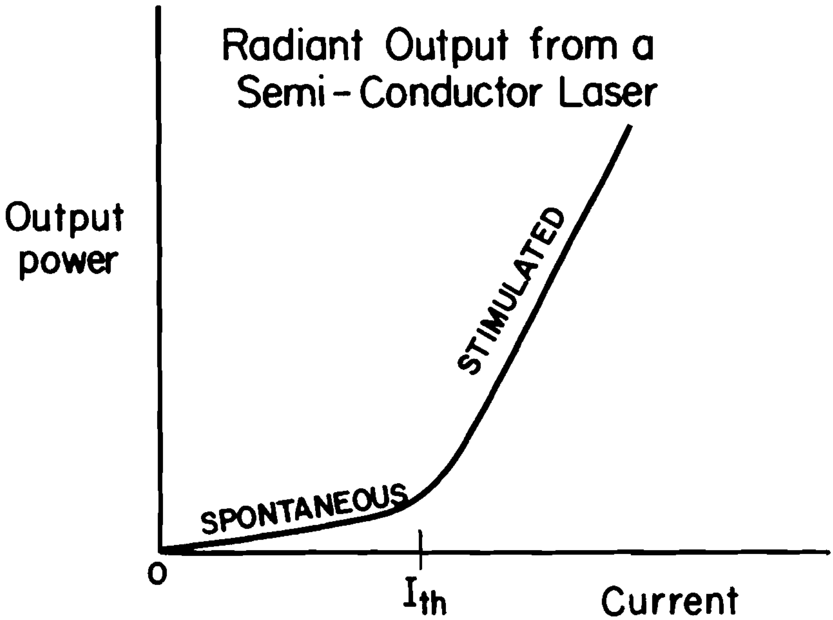


Figure 4.

Unlike gas lasers, laser diodes are solid state, considerably more efficient, more compact, more stable, need only low voltage power supplies, and last much longer.

Table I compares a few gas lasers with the laser diode.

LASERS USED IN GRAPHIC ARTS APPLICATIONS

| Type | λ nm | Power | Efficiency | Weight | Cooling | Lifetime Hrs | Price |
|---|---|---|---|---|---|---|---|
| Argon Ion | 448,514.5 (351-515) | 5mW-20W | 0.01-0.1% | 10-300kg | Water/ forced air | 1000- 10,000 | $3,000 ($50,000) |
| HeCd | 325,422 | 2-40mW Vis 1.5-10mW UV | 0.1% | 10-20kg | Air | 4000 Vis 2000 UV | $ 3,000 ($10,000) |
| HeNe | 633,1152 3391 (612,604, 594) | 0.1-50mW | 0.01-0.1% | 1.5- 100kg | Air | 5000- 100,000 | $200 ($15,000) |
| NdYAG | 1064 (1320) | 0.04-600W | 0.1-2% | 30- 700kg | Water | 200 (arc lamp) | $3,000 ($90,000) |
| Laser Diode | 780-905 | 1-40mW | 1-20% | <1g | Air, heatsink | 10,000- 1,000,000 | $50 ($2,000) |

Table I.

One of the most significant properties of a laser diode is that it can be directly modulated at the rate of several GHz. Figure 5 illustrates the relationship between output power and current applied to a 5 mW Hitachi diode.[8] As can be seen, a small difference in the applied current results in effective on/off of the diode emission. This means that there is no need for an external modulator. Optics are simpler, bringing higher optical efficiency to the system.

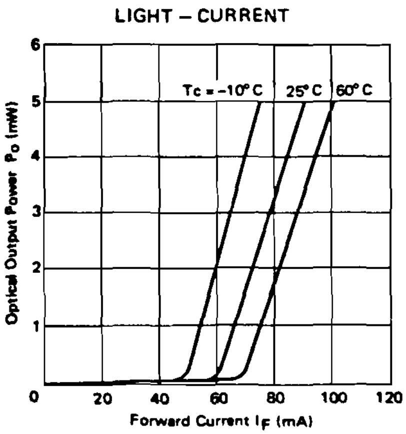


Figure 5. Output power vs. forward current relationship for a HITACHI HL7801E Laser Diode.

The cost of a low-power laser diode is almost negligible when compared with similar power gas lasers. With expected lifetimes approaching 1,000,000 hours, they can easily outlive the equipment that houses them.

The laser diode emits a coherent beam that is not collimated. It emits a diverging ellipse with approximately a 1:2 aspect ratio. With an appropriate collimating lens, this diverging beam can be collected and collimated to desired beam widths. Figure 6 is a plot of the desired numerical aperture of a collimating lens for a given beam divergence.

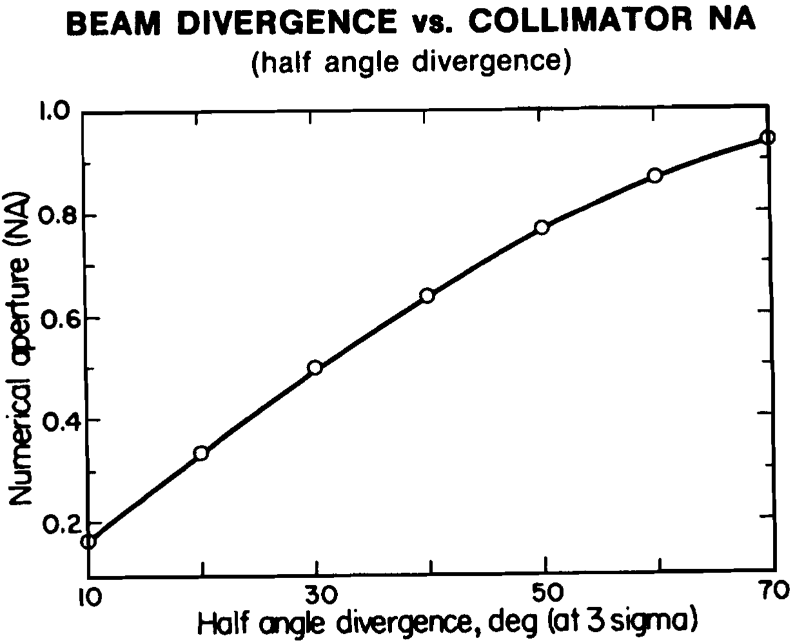


Figure 6.

As indicated above, the laser diode is an inherently superior source of energy. It has found wide-ranging applications in the last two decades. Optical memories, communications, reprographics, and consumer electronics are some of the popular applications. Its growth has been far ahead of any other type of laser in the last 5 years.

The laser diode has the potential to become the dominant laser for graphic arts applications. It meets all the requirements for applications in high speed recording systems. In addition, it is also the most compact, reliable, and least expensive light source.

Indeed, the laser diode has already made its debut through Ultre's Ultresetter output writer (Ultre Corporation, NY). The advantages of laser diodes manifest themselves in this equipment -- in the simplicity of its design, in its compact size, its high resolution output, and its output speed. Yet, it is the least expensive output writer in its class on the market today.

The properties of the laser diode present the graphic arts industry with tremendous potential for the design of an entirely new generation of recording hardware. However, there is one critical factor that must be addressed. In order to design such equipment, there must be photographic material suitable for exposure by laser diode.

## Laser Diode-Exposable Photographic Materials

In recent years, the development of photosensitive materials has paralleled the development of new laser light sources. Today, there are several photographic films, papers, and plates on the market designed to respond to the unique spectral emissions of a number of lasers.

Of course, producing photosensitive materials for laser exposure involves much more than the issue of spectral sensitivity. In order for a material to be suitable for use, it must incorporate the following attributes: appropriate appropriate spectral sensitivity, adequate photographic speed, high contrast, high density, and low image spread (modulation transfer function). The material must also be thermally stable for long shelf life. Anti-halation protection is required, as well as good latent-image-keeping, reciprocity, and intermittency characteristics.

The challenge for designers of photographic products is to incorporate all these attributes in laser-exposable materials. Of the above attributes, the spectral sensitivity, photographic speed, and anti-halation protection are unique to a given graphic arts film.

A major design criterion was spectral sensitivity. Graphic arts materials rarely extend beyond 650 nanometres of the electromagnetic spectrum. Photographic materials have an intrinsic sensitivity in the blue region (i.e., $<$510 nm) of the spectrum. To match the output of laser diodes, the materials have to be sensitized for exposure in the nonvisible near-infrared area of the spectrum. Spectral sensitivity to longer wavelengths is accomplished by adsorbing spectral sensitivity dyes to photographic emulsion grains. In very general terms, these dyes absorb photons of longer wavelengths and effect an electron transfer to the silver halide grain. This, in turn, results in the formation of the latent image.

Several years ago, Kodak recognized the laser diode as a potential light source for graphic arts applications. It also recognized the need for a family of infrared-sensitive, stable, high contrast graphic arts quality photographic film and paper materials. Kodak has developed such materials for exposure by laser diode. The materials are KODAK ILD Phototypesetting Film (SO-156) and KODAK ILD Phototypesetting Paper (PX-2622).

These materials have a near flat response between 780 and 810 nm and are not more than 20 percent slower between 760 and 820 nm (Figure 7). They are designed to accommodate a wide range of laser diodes.

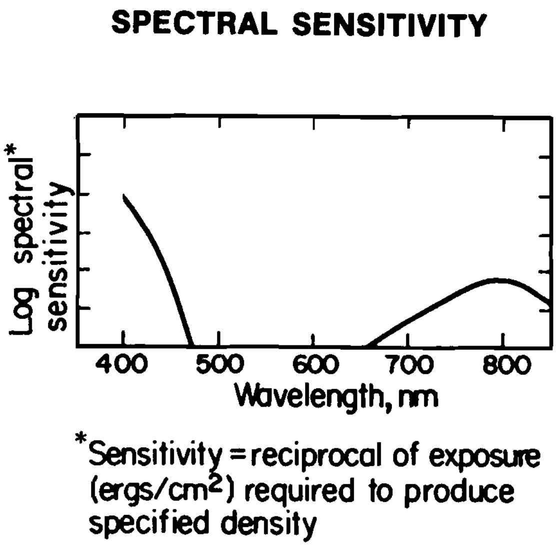


Figure 7.

The characteristic curves for the film and paper are reproduced in Figures 8 and 9. The energy required for optimum exposure of both film and paper is the same: 50 $ergs/cm^2$. As a result, both film and paper can be exposed at the same speed to achieve the optimum density for each. Fifty $ergs/cm^2$ is well within the capacity of a 3 milliwatt laser diode.

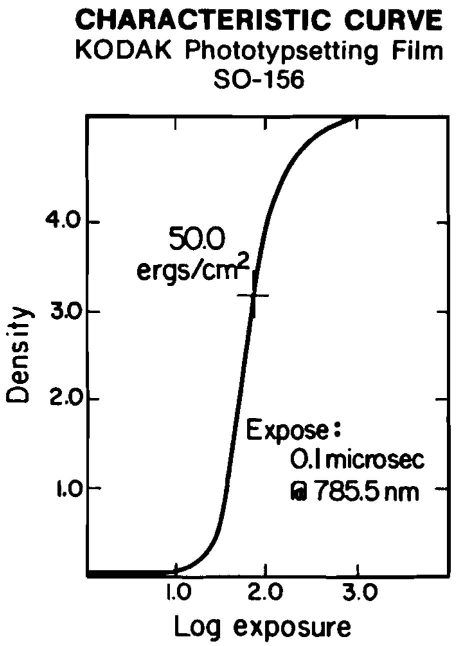


Figure 8.

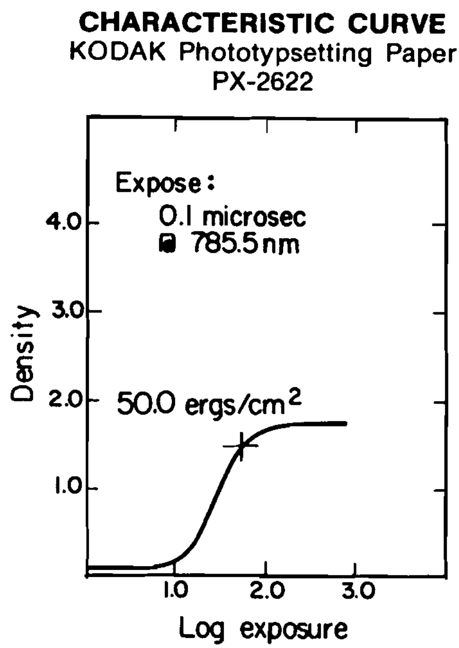


Figure 9.

A prime concern in the design of the new KODAK ILD Products was stability. In the past, materials sensitized for infrared exposure tended to react to heat and were highly unstable. These characteristics have been designed out of our new products. Measuring film speed stability allows us to determine whether normal storage of the material prior to use will affect its performance. Speed stability has been tested over a period of 11 months and has remained well within the bounds of acceptable deviation (Figures 10 and 11).

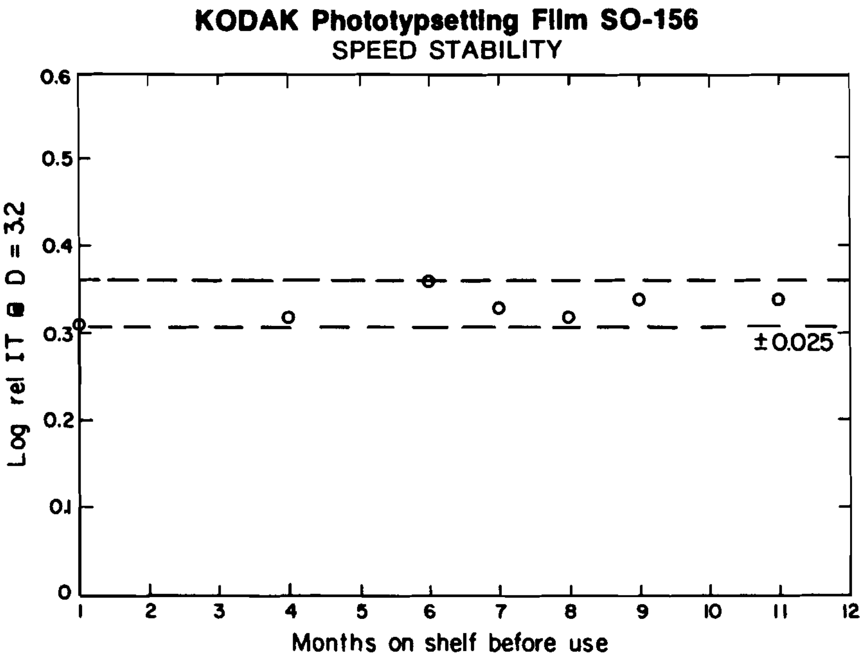


Figure 10.

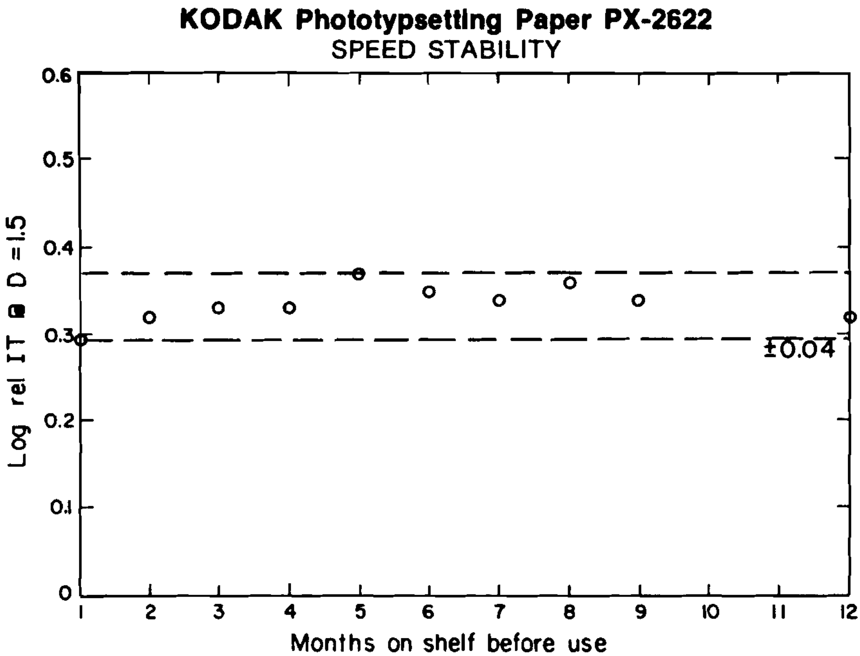


Figure 11.

These products are designed to behave the same, regardless of the exposure times, over a range of 5 microseconds to 50 nanoseconds (i.e., 200 kHz to 200 MHz data rate range). This is a measure of the reciprocity characteristic (Figures 12 and 13).

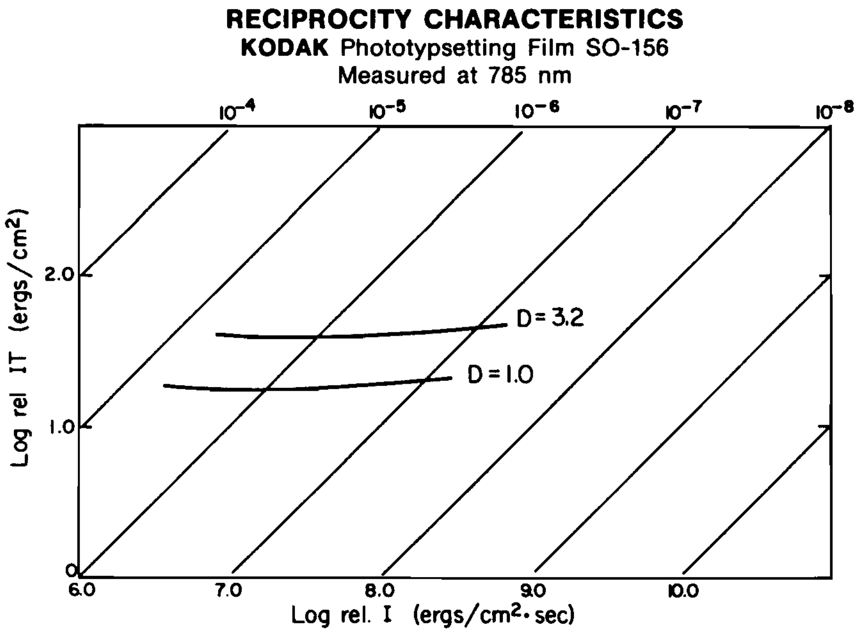


Figure 12.

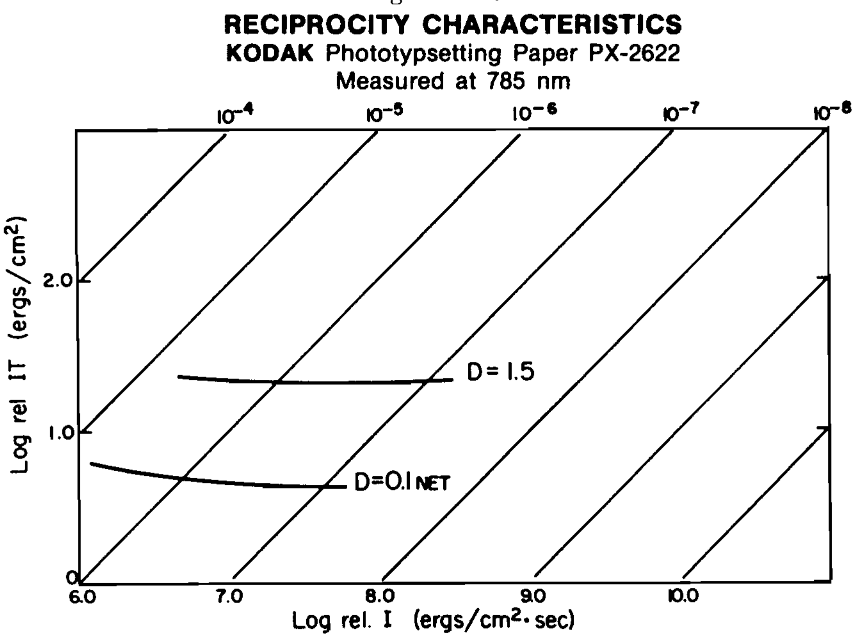


Figure 13.

Another factor that is becoming more important in the graphic arts field is the safelight issue. These products can be handled for several minutes with a green KODAK 7 Safelight Filter.

The latent image keeping, as shown in Figure 14, is designed to be stable for several days.

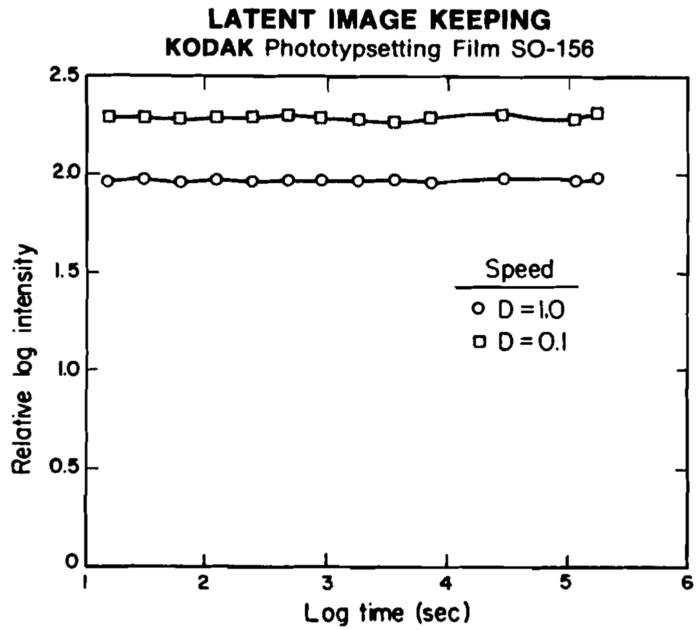


Figure 14.

These new products can be developed in rapid access processors. Paper and film can be intermixed without changing chemicals. They can also be processed together in more than one chemistry under a variety of conditions.

The image quality of these new products is designed to be superior to that of current phototypesetting products. This is the result of the type of photographic emulsion used. In order to maintain optimum image quality, the film is also protected from halation effects. Figure 15 is a comparison of density profiles of a 23 micrometer raster line exposed on films both with and without antihalation.

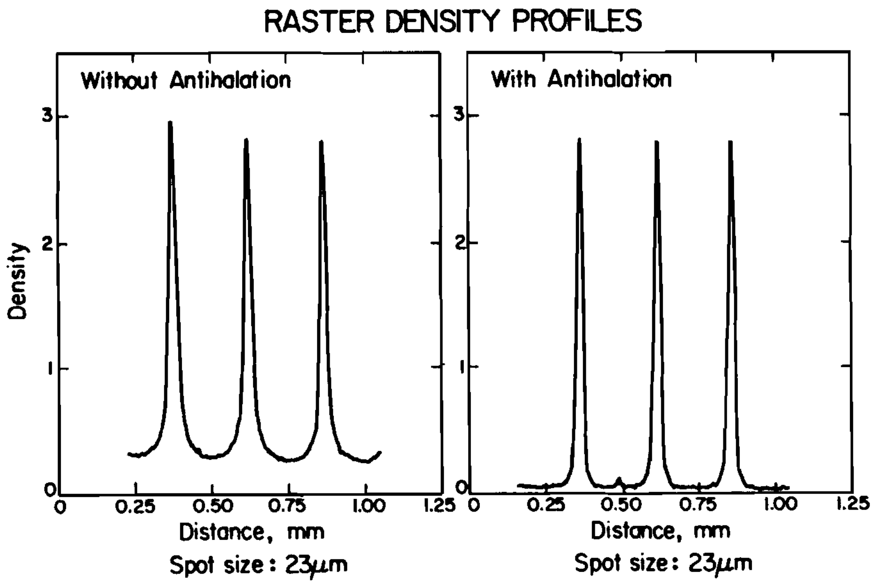


Figure 15.

Comparison of image quality of these products exposed on the Ultre Ultresetter laser diode output writer with comparable output from a variety of gas laser recorders demonstrates a clear improvement in edge definition and overall image quality.

This product is already being used for phototypesetting applications by several printer around the world. The use of laser diodes for high-quality graphic arts applications is now a reality. We at Kodak continue to explore this technology for a number of other related applications. There are challenges that await us. However, as we proceed with our research, we are confident that those equipment manufacturers currently engaged in the development of laser diode imaging systems will succeed.

We believe that its unique mix of price and performance will make the laser diode the dominant light source for graphic arts in the future.

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Note: KODAK is a trademark.