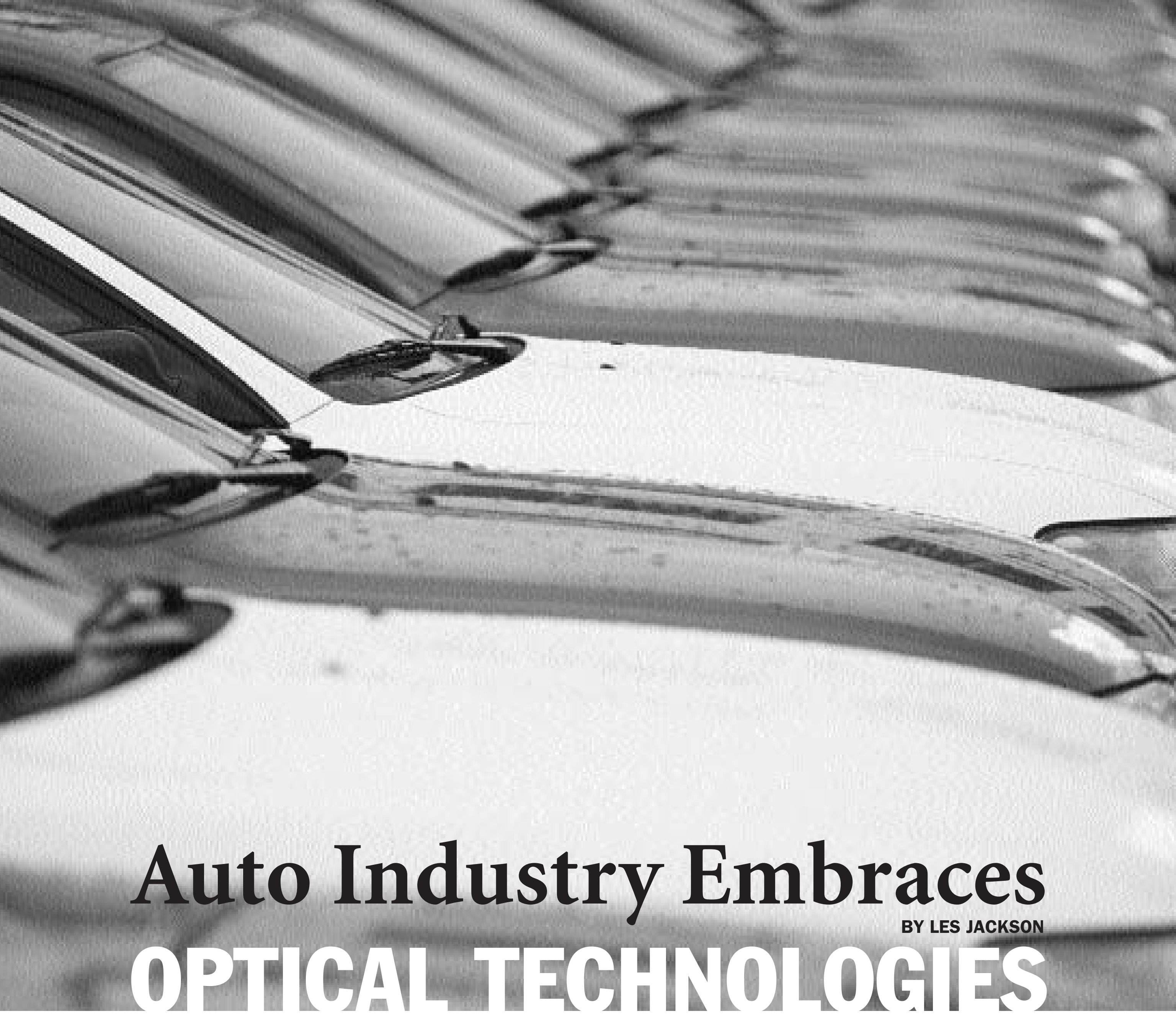

# Auto Industry Embraces OPTICAL TECHNOLOGIES

BY LES JACKSON

THE AUTO INDUSTRY IS AN ENORMOUS proving ground for technological advances, exceeded only by the defense and aerospace industries. These advances have chiefly been in the areas of metallurgy, electronics and emission controls, all of which have had to meet the rigid cost constraints of the automobile industry.

Historically, the use of optical devices—other than mirrors and focusing lenses for lamps—has been limited. Exceptions include optical fiber (as lamp monitors on late-60s Corvettes and Cadillacs), photocells (as headlamp dimming switches in the late 1950s) and IR sensors (principally as back-up warning systems for trucks). Until very recently, in fact, the auto industry's cost constraints have precluded the use of optical devices. Now, however, the situation is rapidly changing. Several new optical-based products


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are already (or will soon be) available as factory-installed or aftermarket equipment. Two particularly significant technologies are "smart glass" and night vision systems.

## Smart glass

Manufacturers of automotive glass are hungry for glazing solutions that offer effective and controllable darkening capabilities without consuming large amounts of electric power. The industry wants to limit air conditioning loads on vehicles, chiefly because of Corporate Average Fuel Economy (CAFE) regulations, and also reduce assembly and materials costs for such items as sunroofs and tinted glass. So important is this issue for the long-term, the federal government now funds research into glazings under an annual $500,000 grant to promote technology that reduces accessory loads and materials processing emissions.

For safety considerations, U.S. regulations require that all windows in vehicles be at least 70 percent luminous transmitting (normal incidence), weighted to Standard Illuminant A (a tungsten filament at 2854K). European standards are comparable.

Industry marketing surveys estimate that vehicle glazing surface areas will increase by 25 percent or more over the next several years, as styling and accessory demands dictate. Therefore, the industry is looking for some kind of switchable technology that isn't much more expensive than conventional glass. Such technology must quickly adjust its transparency and (ideally) remain dark when the vehicle sits; in short, "smart glass." In a perfect world, smart windows would transmit the full solar spectrum during cold winter months but reflect all incoming near infrared solar radiation in summer, while allowing the driver adequate visibility.

Two technologies are currently under consideration: suspended particle devices and electrochromics.

## Suspended particle devices

A promising newcomer in the automotive glazing field is the suspended particle device (SPD), the domain of Research Frontiers, Inc., of Long Island, NY. Capitalizing on a technology discovered nearly a century ago, company founder and president Dr. Robert Saxe has spent three decades developing a product that shows great promise for solving automotive as well as industrial glazing problems.

SPD operates on the principle that particles of Herapathite (a combination of quinine sulfate and iodine) absorb light in their natural state. If a current is applied, however, the particles align to allow light to be transmitted. Further, alignment is linear with respect to the current applied, so the level of darkening can be controlled predictably.

Light incident on this film is strongly scattered from the liquid crystal/polymer interfaces, resulting in an opaque panel in the unpowered state. When a voltage is applied to the transparent conductors, the liquid crystal molecules align in the electric field, resulting in an apparent refractive index that is similar to the polymeric matrix. This occurs because the liquid crystal molecules are birefringent (refractive index parallel to molecular axis differing from that perpendicular to this axis). Thickness of the encapsulated crystal layer is in the order of 10 to 100 microns.

Suspended particle devices are driven at an alternating voltage (sinusoidal or square-wave) between 50 and 100 volts and response time varies with temperature, with typical times at room temperature being 1 to 100 milliseconds—essentially instantaneous for automotive applications.

The refractive index match between the suspended particles and the polymer matrix changes with the angle of observation, possibly limiting certain automotive applications such as windshields.

No one has produced a commercial SPD product to date, but the potential is enormous. For instance, one of

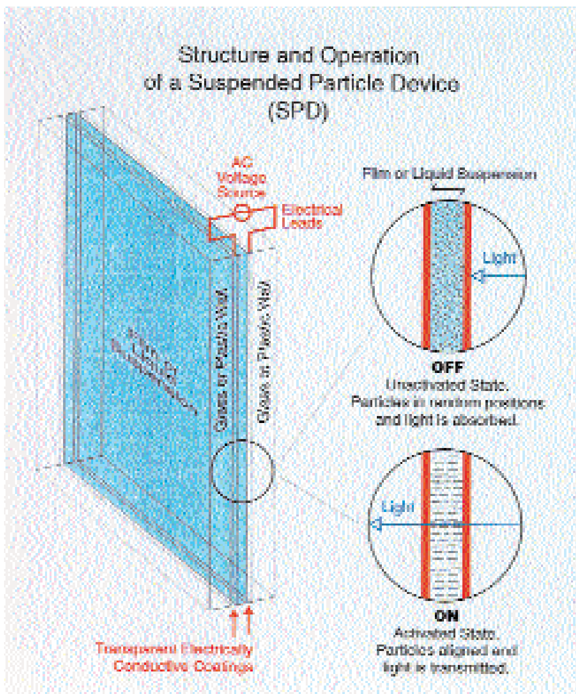


**Figure 1.** Structure and operation of a suspended particle device (SPD).

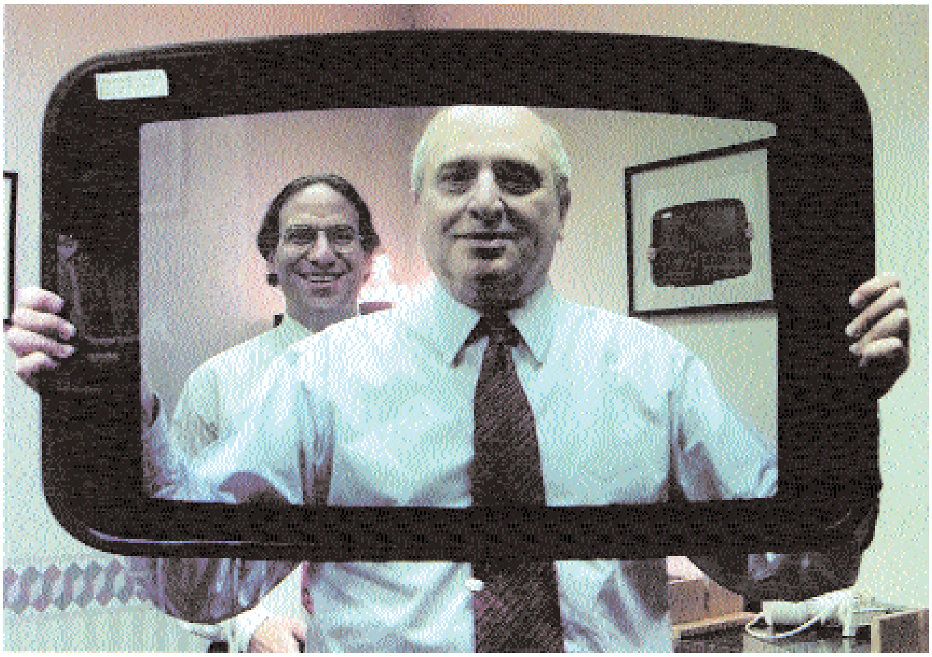

**Figure 2.** Saxe looking through prototype sunroof. (Newsday, Inc. Copyright 1999. Reprinted with permission.)

the most lucrative automotive aftermarket products is the sunroof. Thousands of shops around the country install accessory sunroofs on new and older vehicles and there is no end in sight to this over $1 billion market. SPD film technology has the ability to conform to any shape and to adhere to any material, allowing great versatility for sunroof designs. In addition, since the system is dark when the vehicle is parked, no inner shield is required, so intrusion on the vehicle's interior can be minimized. Also of great benefit is the fact that there is no current drain when the system is in the dark mode.

Self-dimming mirrors represent huge potential in a market that has grown at an annual rate of 35 percent since 1992. Industry analysts predict that eventually one half of the 50 million vehicles produced yearly will contain an automatically dimming mirror. SPD technology fits this market very well, since such mirror surfaces can change faster than currently-used electrochromics, not only from light to dark (to minimize glare to the driver's eyes) but back to high-reflectance to permit good visibility when conditions require it.

## Electrochromics

The automobile industry has embraced electrochromic devices in the form of rearview and outside mirrors, and considerable study into their use for overall glazing is underway. Electrochromism is a reversible color change in a material induced by an applied electric field. Electrochromic devices may be:

- thin film electrochromic (EC) devices, in which coloration occurs due to redox reactions in inorganic metal oxide thin films such as tungsten oxide, molybdenum oxide, iridium oxide, or nickel oxide;

- electrochemichromic (ECC) devices, in which coloration occurs due to redox reactions in chemical solutions, typically of organic materials such as viologens, diamines and phenazines.

Electrochromic materials change color either cathodically (with the application of negative voltage), or anodically (with the application of positive voltage). A schematic of a typical thin film electrochromic device is shown in Figure 3.

Such a device consists of (1) a working electrode that colors; (2) a counterelectrode that is a sink and source for the ions used during coloration of the working electrode; (3) an electrolyte that separates the working from the counterelectrode; and (4) conducting layers that provide electrical contact to the electroactive layers; for automotive applications, these conducting layers must be transparent, so conductors such as indium tin oxide are used.

Solid-state and liquid gel electrolytes are used in electrochromic devices. In a solid-state application, the complete electrochromic device can be a stack of thin films deposited onto a single substrate, shown by Figure 4.

In liquid gel applications, a laminate electrochromic design consisting of two substrates sandwiched together by the electrolyte is used (Figure 5).

Whether devices are solid-state or laminate, thin film electrochromic devices retain their color even when the coloring voltage is removed. This property, commonly referred to as "memory," is the effect desired by automotive engineers because the glazing will remain colored for prolonged periods while the vehicle is parked.

With electrochemichromic materials, the degree of coloration can be user-controlled by varying the applied voltage or the duration for which it is applied. When a small voltage is applied across the indium tin oxide conductors on the inwardly facing surfaces of the two glass substrates, the chemicals in the fluid solution color, thus lowering transmission through the window. When the voltage is removed, the window self-erases to its transmitting, "bleached" state. This technology is used in automatically dimming rearview mirrors, commonly found as options on General Motors and Ford vehicles, as well as many other luxury cars.

Worldwide, most major automotive glass companies have programs directed at electrochromic glazing. Asahi Glass Company in Japan has developed a laminate thin film electrochromic construction consisting of two indium tin oxide coated glass substrates (one of which is coated with about 6000 angstroms of tungsten oxide), sandwiching a semisolid gel electrolyte. This device controls visible transmission within the range 80-percent T to about 10-percent T. In the dimmed state, solar transmission is as low as 6 percent of the total integrated spectrum, as shown in Figure 6.

Response time of electrochromic devices is dependent upon the size of the window and the sheet resistance of the transparent conductors (for example, using 10 ohms/square indium tin oxide as the conductor, a 4cm x 4cm window dims to 30 percent T in five seconds, whereas a window 10 times as large would take about two minutes). Once colored, however, the degree of tinting remains unchanged for long periods of time unless a reverse current is applied. "Memory" is dependent upon the degree of coloration as well.

Laminate electrochromic windows using a phosphoric acid/poly (oxyethylene) polymeric electrolyte (developed by Saint-Gobain Vitrage, France) and another using a polymer electrolyte and a copper mesh counterelectrode (developed by PPG Industries) have both shown wide ranges of luminous transmission (78 percent to 32 percent in the former and 70 percent to 20 percent in the latter) within acceptable time limits and low current densities.

## Automotive considerations

From the perspective of automotive engineers, any glazing system must conform to size and shape parameters, necessitating development of devices for which the complete electrochromic stack or SPD film can be deposited onto a single substrate which can itself be laminated. Further, if such devices are to be used in windshield applications, high transmission must always be guaranteed in situations involving power loss.

Additional challenges to those developing smart glass technologies are the necessity for minimum visual distortion, integrity of the glazing during crashes, low current demands on the vehicle's battery and long-term resistance to UV exposure.

Last, glazing systems must be cost-effective: when it comes to automotive products, there is little price flexibility on the part of original equipment manufacturers (OEMs) unless the component can add significant value that can be passed along to the consumer in the form of optional equipment charges.

## Night vision systems

The military has relied on thermal imaging systems for decades. The ability to "see" in the dark has yielded tremendous advantages to battlefield combatants, as was demonstrated so effectively in the 1991 Gulf War. Target acquisition, fire control and pilotage are dramatically improved with night vision.

Automotive safety engineers have long sought a civilian version of night vision systems to augment the driver's ability to see beyond the range of the vehicle's headlights. However, no affordable systems were commercially available for automotive use until Raytheon Systems Company developed new, low-cost production technologies for certain infrared optical components. Those technologies have resulted in the first commercially installed automotive night vision

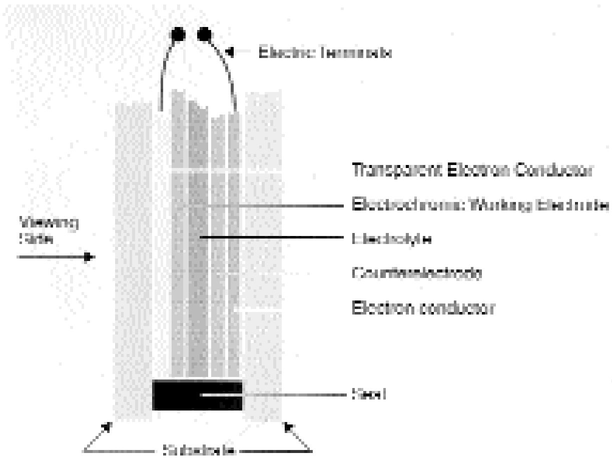


**Figure 3.** Schematic electrochromic thin film.

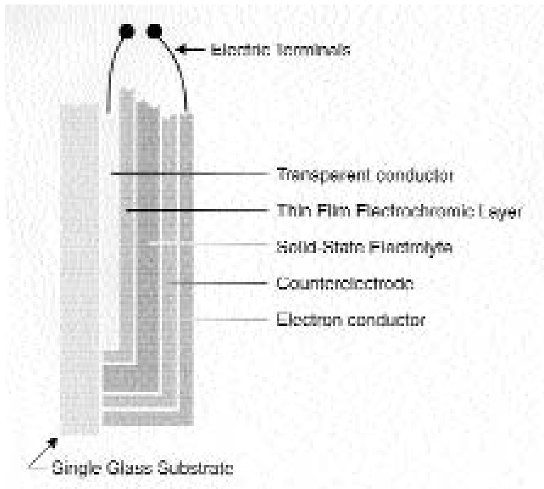


**Figure 4.** Solid state schematic.

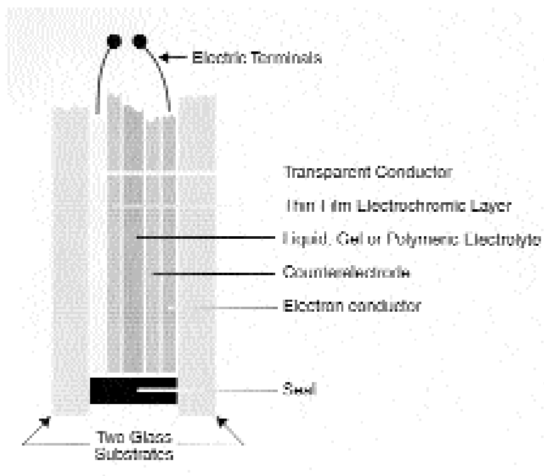


**Figure 5.** Liquid gel schematic.

system, now available as an option on the 2000 Cadillac DeVille.

The DeVille system consists of a front-mounted IR camera and dash-mounted optical module which projects on to the lower windshield. The heads-up display

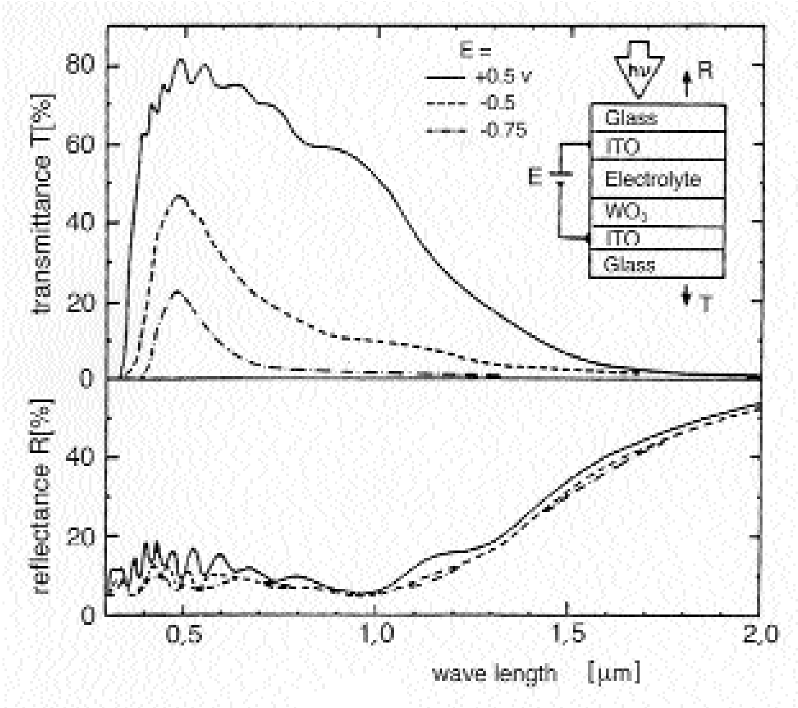


**Figure 6.** Solar transmission graph.

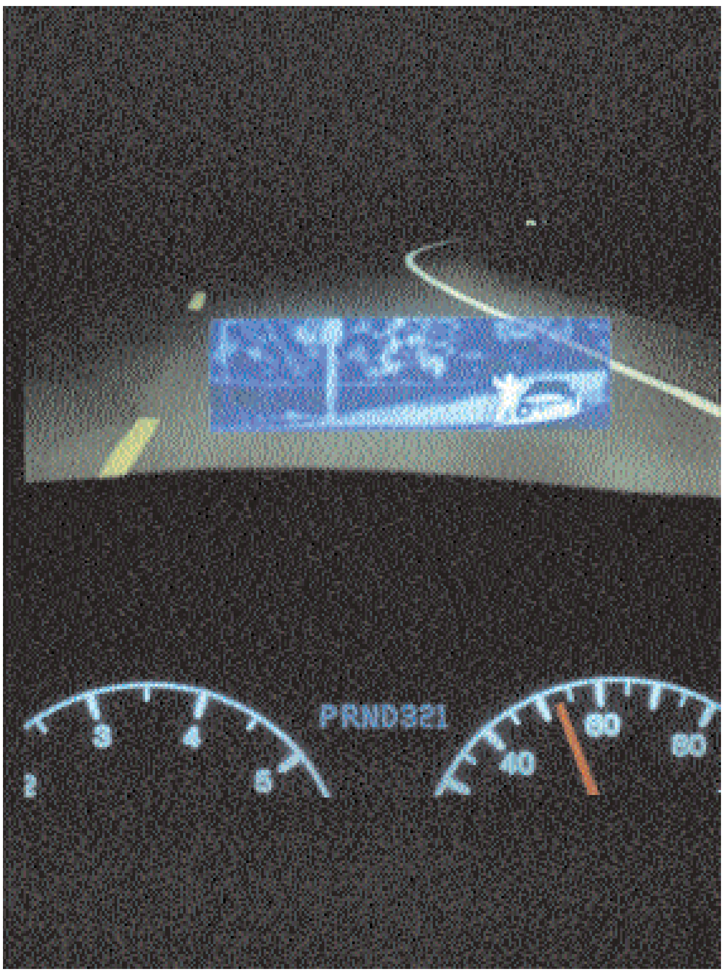


**Figure 7.** Typical view in windshield.

provides the driver with a good-contrast black-and-white image of objects ahead, as much as five times the distance visible with the headlights.

To make an automotive system, a completely new way of manufacturing was required. In late 1995, Raytheon engineers realized that although component cost trends in infrared detectors and electronics had significantly dropped, optics themselves remained expensive (prohibitively so for automotive use). Conventional aspheric, diffractive infrared lens fabrication processes were too time-consuming for economical automotive use. The company then committed to fully develop and transition to produce various technologies learned through a program funded jointly by the Defense Advanced Research Projects Agency (DARPA) Technology Reinvestment Program and the U.S. Army Night Vision and Electronic Sensors Directorate (NVESD). The program provided millions of dollars to develop low-cost precision infrared optics.

As a direct result of the research programs, Raytheon began introducing new, lower-cost precision infrared optics in 1997 at its ELCAN-Texas Optical Technologies facility in Dallas. This factory has produced thousands of infrared imagers, polymer windows, and polymer choppers for law enforcement and security professionals.

Raytheon developed a replication process to produce precision aspheric glass lenses from low-cost infrared transmissive glass, using less labor and material. To eliminate precision machining, kinoform diffractive optical element patterns for chromatic aberration correction are fabricated directly on the lenses before coating, allowing optical systems to use fewer optical elements. The infrared-transmissive glass used yields high transmission at high temperatures and low refractive index rate of change with temperature. These are both important considerations for automotive use. The glass outperforms germanium in these areas.

Polymer window assemblies replicated with sub-wavelength surface anti-reflection structures that rival the optical performance and exceed the strength of conventional windows are produced at a small fraction of the cost of conventional windows. Replicated microlens polymer chopper assemblies are used in place of conventional choppers, again at a small fraction of the cost. Components are precision injection-molded with tolerances of less than 1/1000th inches.

Replicated true kinoform diffractive polymer lenses replace more expensive (and heavy) glass lenses in imager designs. Paul Klocek, manager of ELCAN-Texas, said of the technology, "We had to revolutionize the infrared optics industry to respond to Cadillac's needs in the commercial sector. In responding, we invented these technologies, providing us a ten-fold increase in productivity which can be exploited by all infrared systems customers, both defense and commercial. A few dozen people can produce hundreds of thousands of components."

Raytheon's five-year program required the development of materials technology, coatings technology and many other processes, all of which had to be cost-effective. The components now being produced for Cadillac have been life-tested to exceed 10 years (typical 100,000-mile time frame), at temperature ranges from -40° C to + 105° C.

The Heads-Up Display (HUD) portion, which includes system optics, is modular and serviceable as well as extremely compact, as dashboard space is always at a premium in automotive design. The module uses passive athermalization with temperature-compensated plastics and no adhesives.

## Sources


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2. Niall R. Lyman, "Smart windows for automobiles," Donnelly Corporation.
3. Robert Saxe, Patricia Bryant, Research Frontiers Incorporated.
4. Paul Klocek, Raytheon ELCAN-Texas Optical Technologies.
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## Emerging Applications

The automotive industry is driven by two, often competing, forces: customer demand and government regulation. Customers demand the latest features that provide enhanced safety, comfort, performance, style and reliability. Every feature added to a vehicle increases its weight, however, and government regulations (such as CAFE and EPA emissions rules) challenge automotive engineers to trim vehicle mass and size to reach acceptable compromises.

Current and future automotive design problems offer great potential for optical solutions.

### Fiber optics

As vehicle electrical systems and power assists have become more complex (power assists are now standard equipment on most vehicles), the amount of wiring in cars and light trucks is a critical concern. Sheer weight of wire is now exceeding 50 pounds in many luxury vehicles and the expense in material and labor cuts profits at the assembly level.

Manufacturers are looking to convert much of the vehicle's electrical circuitry to optical fiber, especially in applications that require systems integration—such as engine control, transmission control, climate control, navigation and sound systems. Mercedes-Benz, BMW and GM have taken the first steps toward integration of optical fiber into vehicles and most other manufacturers are soon to follow.

Benefits of a switch to optical fiber include weight savings, simplicity of assembly and potential increase in reliability of vehicle electrical systems, chiefly from a reduced number of connections.

### Infrared sensors and cameras

Already utilized in night vision applications, IR sensors and cameras are being considered for other vehicle systems such as "smart" cruise control, "smart" air bags and owner-recognition systems.

Cruise control systems can be designed to recognize input from the vehicle's IR camera to warn drivers of obstacles ahead, even to the extent of taking control of vehicle braking or throttle. Most manufacturers have developed such systems for test but legal considerations have so far prevented their use.

Air bag safety has become a controversial issue, with injuries to children and elderly persons numbering in the hundreds. The National Highway Traffic Safety Administration (NHTSA) is encouraging manufacturers and OE suppliers to develop smart air bags. Several systems have been developed using pressure transducers and other mass-sensing devices to dictate how (or if) the bag deploys, but such systems cannot accurately show the person's position and stature predictably. Therefore, some air bag manufacturers are considering IR sensors to "paint" a picture of the person sitting in the seat, allowing a far more accurate "decision" on how to deploy the bag.

Consumers desire increasingly sophisticated vehicle entry systems, and manufacturers are working to develop an owner-recognition system which will reliably "see" an approaching person, recognize that the person is authorized to enter and drive the vehicle, then unlock itself. IR camera-based systems which have that capability are under development. In the future, it is likely that vehicle owners won't need to use keys or remote devices for either entry or operation.