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MASTER

PLZT THERMAL/FLASH PROTECTIVE GOGGLES: DEVICE CONCEPTS AND CONSTRAINTS*

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In 1975 Sandia Laboratories began the design and development of PLZT Goggles for the U.S. Air Force to provide protection from temporary flashblindness and permanent retinal burns caused by the brilliant flash of nuclear explosions. The user requirements, system and physical constraints, and use/storage environments were all considered in arriving at the final design goals. When the program began, there was no industrial capability to manufacture large-aperture PLZT materials or bonded lens assemblies. The technology has been established from a laboratory baseline in a brief period, and operational testing and evaluation by the Air Force has been completed. The goggles, identified as the EEU-2/P, are now in production.

INTRODUCTION

Lead zirconate-titanate (PZT) ceramic materials, modified by the addition of small amounts of lanthanum to replace some of the lead, were developed by G. H. Haertling at Sandia Laboratories in 1969. The new ceramic materials became identified by the acronym "PLZT." They displayed a new and exciting physical property for electronic ceramics -- optical transparency. The materials were ferroelectric and, predictably, electrooptic. These characteristics were extensively investigated by Haertling, Land, and Thacher, and a wide range of behavior was categorized.[1,2]

As a result of promptings and inquiries from visiting military officers who witnessed demonstrations of PLZT displays and shutters at Sandia, a simple prototype of a PLZT flashblindness goggle was first assembled in 1971. This system was shown to USAF personnel at the Air Force Weapons Laboratory, Kirtland AFB, NM. Encouraged by them and other military agencies, improved prototypes were developed. This resulted in a small, totally self-contained device housed in a conventional laboratory goggle frame and powered from a 5-volt mercury cell.[3]

In 1973, the Atomic Energy Commission (now Department of Energy) was asked by the USAF to initiate a reimbursable program at Sandia Laboratories for the development of a prototype 6 x 8-inch thermal/flash protective device (TFPD) window. This system was fabricated using a mosaic arrangement of four 3 x 4-inch PLZT lenses and a small battery-powered electronic supply. One of the primary tasks during the development was a scale-up in PLZT hot-pressing technology to manufacture 5.25-inch diameter slugs of acceptable optical quality.[4]

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The PLZT/TFPD window was demonstrated in the summer of 1974. About this same time, the Life Support Systems Program Office was tasked by the Air Force to develop an active TFPD goggle to meet operational requirements of the Strategic Air Command. After evaluating competing systems and technologies, a tri-service study committee recommended that a PLZT/TFPD goggle be developed by Sandia Laboratories to meet this requirement. Work began in 1975. The resulting goggles, identified as the EEU-2/P Goggles, Flyers, Flash Blindness, are shown in Figure 1.

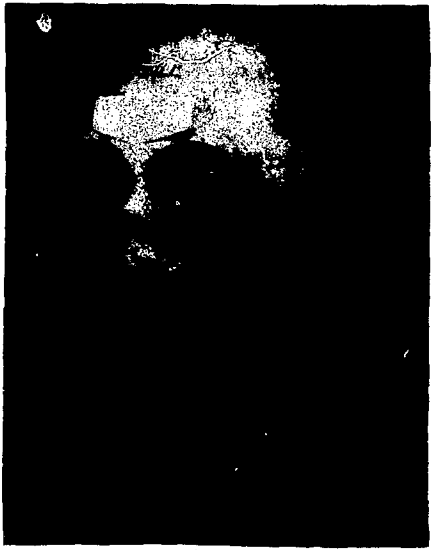

FIGURE 1. EEU-2/P flashblindness goggles.

DEVICE CONCEPTS, CONSTRAINTS, AND OPERATIONAL GOALS

The operating principles of the PLZT/TFPD goggles are rather simple and have been fully described elsewhere.[5] The lens consists of an interdigitally-electroded PLZT wafer properly aligned and sandwiched between crossed polarizers in the classical Kerr-cell configuration. An infrared-absorbing filter glass is used on the front side of the lens assembly. In spite of the simple concept, considerable process and material development has been required to reach a production status. The magnitude of this lens development was certainly not fully anticipated at the inception of the program. Many well-defined manufacturing and processing technologies being utilized in optics and electronics at that time were thought to be directly applicable to the manufacture of the PLZT lenses. In fact, little direct applicability was found, and an entirely new technological base had to be established.[6-12]

Because of the state-of-the-art in PLZT technology in 1975, the EEU-2/P goggles could not be developed to a formal specification. Rather, a number of operational goals were established for the device, based on the known and extrapolated data at that time. It was originally anticipated that the greatest effort and cost would be the establishment of an industrial capability to manufacture large-diameter PLZT slugs. This was indeed a formidable task, but the groundwork had been done at Sandia during the mosaic-window program, and the basic processes were well understood. The transition of these processes to a production scale called for innovative and carefully controlled procedures which have now resulted in excellent materials.[7,8]

The primary task at the beginning was the selection of a PLZT composition which would provide the widest range of operating temperatures within system constraints. The X/65/35 family of materials (65% $PbZrO_3$, 35% $PbTiO_3$, with X percent of the Pb replaced by La) was chosen, with X nominally greater than 9 in order to utilize the quadratic electrooptic effect.[5] Since the electronic properties of these materials are temperature-dependent, a detailed investigation of their temperature response was undertaken. Some early work in this activity was reported at the 1975 SAF.[13] The nonpolar-to-polar phase transition was sensitively measured by monitoring "dark-field" electrooptic remanence, and the transition temperature T_t determined for $8 < X < 10.0$.

A system constraint imposed externally was the limited availability of small, high-voltage silicon controlled rectifiers to provide the rapid switching required for flashblindness protection. The practical voltage limitation for these devices was 1200 V. To evaluate the effect of this limitation, PLZT wafers were polished to 0.25 mm thickness, and chrome-gold interdigital electrodes were applied to each surface (electrode line width 76μm, electrode gap 1.0 mm). Half-wave voltage, $V_{\lambda/2}$, and switching characteristics were measured for all compositions over a wide range of temperatures. These data are summarized in Figures 2 and 3. Using these data, we selected the compositional range of 9.35 to 9.60% La. This spread was assumed to be within a production control capability. Switching data indicated that a t_{OD3} of 150μs would be possible down to about 10°C. Since fogging of the goggles would probably occur below this temperature, this compositional range appeared acceptable.

Thus, the operational-temperature goal was established as -12° to 38°C with a capability of switching to an optical density of 3.0 within 150μs over the range of 13° to 38°C. The full military range of -54° to +71°C was the goal for storage.

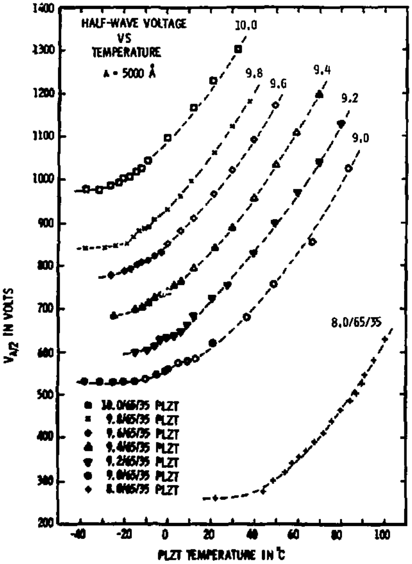

FIGURE 2. Temperature dependence of $V_{\lambda/2}$.

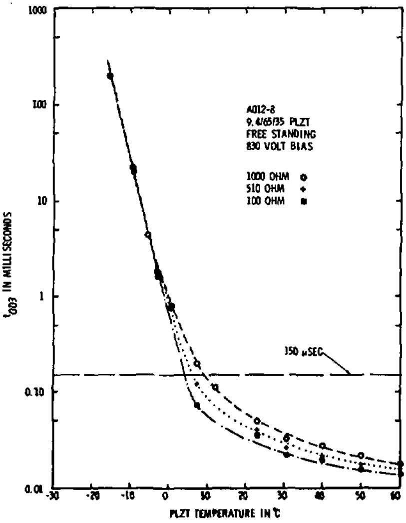

FIGURE 3. Switching speed of 9.4/65/35 as a function of temperature for various discharge resistances. (t_{OD3} is the time required to switch to an optical density of 3.0.)

Other operational goals were that the goggles achieve at least 16% transmittance in the fully-open state, that total weight not exceed 1 pound, and that the electronic controller mounted within the goggles weigh less than one ounce. The actual weight of the goggles is indeed just over one pound; the controller weight falls well within its goal. Open-state *transmittance is typically about 20%.*

The goggles were to withstand windblast, be safe if ejection from the aircraft is required, and survive shock, vibration, high-altitude, rapid decompression, and long-term storage in humid environments. Since the goggles are optical devices, it is clear that many of these environments are limited to the unit in its storage container, which is dessicated. The goggles are also designed to interface only with selected helmets, visors, and oxygen masks.

CONFIGURATION AND OPERATION

The original goal was that the unit utilize PLZT wafers from 3.5-inch diameter slugs. Following flight tests of early prototypes, the maximum dimension of the lenses was increased to 4.0 inches (101 mm). Two versions were evaluated: a two-lens and a four-lens geometry. The latter configuration was chosen for the final design, with 2.75-inch diagonal side lenses and 4.0-inch diameter front lenses (see Figure 1).

The cross section of a PLZT lens assembly is shown in Figure 4. In addition to the components described earlier, a high-order retardation film was bonded between the front polarizer and KG-3 glass filter. The purpose of this film was to eliminate "rainbows" and "dark spots" observed when looking through aircraft windscreens with standard polarizing films. These effects are generated in the windscreens by local stress and are generally noted because of the polarized light in blue-sky environments.

The photodetector used in the EEU-2/P goggles is a phototransistor mounted behind the lens. Its function is to monitor the light in the field of view of the pilot. When a threat (rapid increase in light intensity) is detected by the phototransistors,

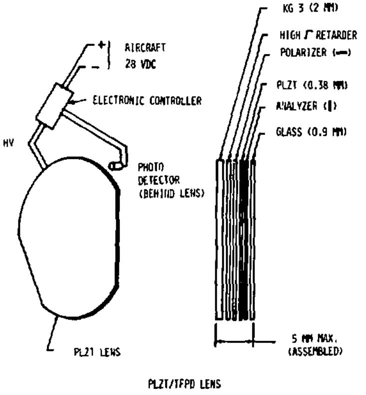

FIGURE 4. PLZT lens schematic.

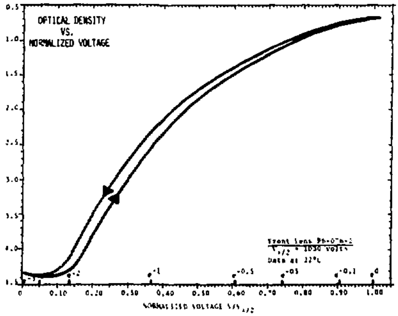

FIGURE 5. Transmittance of a PLZT lens as a function of normalized voltage, $V/V_{\lambda/2}$.

the protection mode is triggered, and the lenses are rapidly discharged by the silicon controller rectifier. The goggles then switch to a servo-electric mode for 20 to 30 seconds. During this time, the light through the lenses is maintained at the pretrigger level, via a memory/comparator circuit, within the optical capability of the lenses. Lens transmittance is shown as a function of normalized voltage in Figure 5.

The electronic controller is a hybrid microcircuit. It operates from the aircraft 28 VDC supply at a current of about 20 milliamperes. It contains all of the logic, servo, and high-voltage-output circuits, and has a push-to-test capability. Temperature compensation provides automatic tracking for the required PLZT lens voltage.

MAJOR DEVELOPMENT AREAS

The major areas of development during this program are outlined in detail elsewhere.[7-12] A brief summary of some of the more significant activities is given below.

Materials

The materials technology was expected to generate the greatest problems, and this has generally been the case. The large-scale PLZT hot pressing technology had to be transferred from the laboratory to industry. This was successfully carried out with one manufacturer, and a qualified success was achieved with another.[7,8]

After manufacture, it is necessary to shape and slice the PLZT slugs, and then the resulting wafers must be polished and electroded. Polishing the thin, polycrystalline materials proved to be extremely difficult. Until recently, only one reliable source existed for production.[9]

The method now being used to manufacture the necessarily perfect interdigital electrodes was nonexistent when the program was started. At that time, the best procedure was vacuum metallization through a mask. Now, an electrode slotting process, utilizing electroless plating techniques, has proven much more cost effective.[10]

It was realized from the outset that the final lens geometry would have to be a bonded lens assembly (BLA) in order to meet the rugged environmental requirements. The conventional bonding methods used in the optics industry proved unsatisfactory for the electrooptic lens geometry. Strains in the bonding materials and stresses transmitted to the PLZT wafer were readily apparent between the crossed polarizers of the BLA and caused a significant degradation in the closed-state optical density. Furthermore, ionic materials and impurities in the bonding agents resulted in a space charge near the electrodes. After an extensive, complex development, a silicone gel has given the best results as the bonding agent with only one minor environmental drawback: a glass transition in the gel at about -55°C limits the lower temperature for storage.[11]

Antireflection coatings on the PLZT have not been satisfactorily developed because of space charge problems with the coating materials. It is anticipated that more work will be done in this area in the future.

Polarizers

When the EEU-2/P development was begun, one goal was to develop a new sheet polarizer which would permit greater transmittance through the BLA. Polaroid Corporation succeeded in this task, producing a new material, HN-38S, which gave a significantly higher open-state transmittance without compromising closed-state performance. A problem which was isolated late in the development, and caused some program delays, was the occurance of localized delaminations in the polarizers during long-term storage at elevated temperatures. The problem was extensively investigated, and a *solution was found by using an alternate laminate geometry.*[12]

Mechanical

Once the **geometrical** interface with the other flight equipment was defined, it became necessary to design an attachment method which would permit rapid donning and doffing of the goggles. The mechanism had to be simple and strong, yet permit a safe fly-away during windblast and ejection from an aircraft. This was achieved by using a hook-and-bail arrangement to attach the top of the goggles to the helmet visor housing with a ratchet-lever arrangement at the sides. The 28-volt electrical connection is also achieved at the hook-and-bail. A thin silicone rubber skirt is used to interface the goggles with the oxygen mask.

Electronics

The functions of the hybrid microcircuit electronic controller have been described above. This unit was manufactured using a thick-film/beam-lead-device technology during development and early production. Due to several design iterations, however, the circuit has become extremely complex and is now packaged at a very high density. Consequently, a new, modular arrangement using chip-and-wire technology will be utilized for most of the production units. It is anticipated that this design will prove to be more reliable and cost effective. All of the required functions are *featured in both designs.*

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