New Luminescent Glasses and Fiber Optic Scintillators for use in X-ray Imaging

Cliff Bueno, (408) 742-7894
Materials Technology and NDT Lab
Lockheed Missiles and Space Co., Inc.
815 E. Middlefield Road
Mountain View, CA 94043

A series of new high resolution luminescent glass compositions specifically optimized for use in x-ray (10-10,000 keV) radiographic applications have been developed at Lockheed Missiles & Space Co. (LMSC) and are now being offered through Collimated Holes, Inc. and other sources. The glass compositions are alkaline earth, gadolinium, terbium loaded silicate glasses that have the following improvements when compared to previously available luminescent glasses:

- Increased x-ray absorption cross section (factor 1.2-1.4 at 400 kV)
- Improved glass luminescence output (1.6 x at 400 kV)
- Reduced lag or afterglow; reduced x-ray energy storage (factor of 10 reduction in afterglow)
- Reduced range of secondary electrons generated which improves spatial resolution (important above 1 MeV)

There are a wide range of aerospace inspection applications that cover the 10-10,000 keV x-ray energy regime employing radiographic techniques. For improved reliability, and enhanced throughput, it is advantageous to perform these inspections in real-time or near real-time. Typically this can be achieved with the use of a phosphor based electronic imaging system where a video (or slow-scanned) camera views an optical image corresponding to the x-ray attenuation pattern deposited onto the phosphor. An example of a high energy real-time inspection (i.e. >1 MeV) is the evaluation of defects in rocket motors, their casings and propellant. On the other hand, there is an increasingly stringent requirement to detect subtle features such as delaminations, micro-cracking and disbonds in low atomic number polymer-matrix and metal-matrix composite materials. These inspections require low x-ray energies (~ 15 keV) to obtain high image contrast. Presently polycrystalline phosphor screens and the non-LMSC developed luminescent glass and fiber optic scintillator (FOS) detectors have been employed for this range of inspections with some success. Luminescent glass plates, at low energy, offer improved sensitivity over NDT film while maintaining comparable resolution to this medium. In some cases these plates can reduce exposure times by a factor of 60 over radiographic NDT film. At high energies, these plates can be made thick to absorb more of the x-ray imaging photons and improve image contrast while maintaining spatial resolution. On the other hand, producing thick, more highly absorbing polycrystalline phosphor screens results in severe spatial resolution degradation due to increased light scattering among particles.

Previous glass scintillators and the FOS produced from them suffered from significant afterglow, which causes blurring in electronic radiographic images. In addition, the x-ray absorption efficiency and x-ray to light conversion efficiency are both lower than desired for optimum image contrast for a given x-ray exposure. All of these problems have been significantly improved with the new LMSC compositions. In addition, the compositions of the materials can be tailored to incorporate the appropriate levels of high Z material for enhanced x-ray absorption efficiency without significant effect on the x-ray-to-light conversion efficiency.

Fig. 1. Absorption Efficiency
as a Function of Energy through 0.25 " Al.

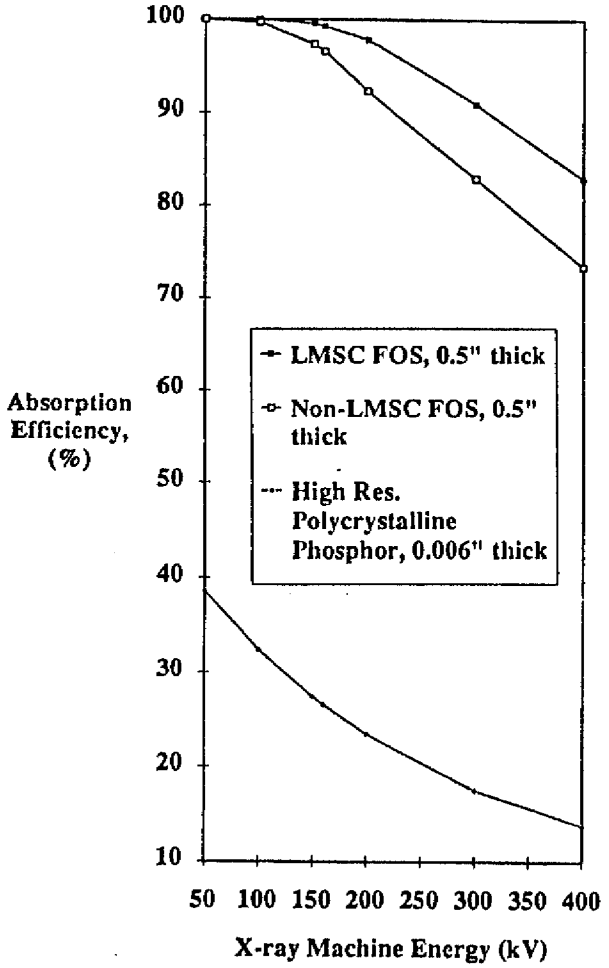


Fig. 2. Light output as a function of x-ray energy
of high resolution screens.
• Through 1 in. Al.
• All FOS plates have reflective mirror backing.

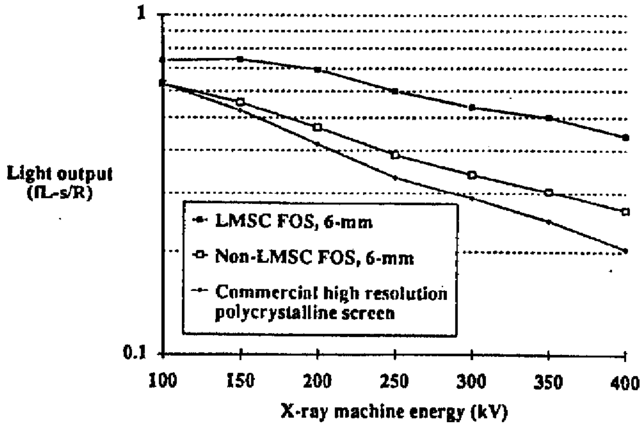
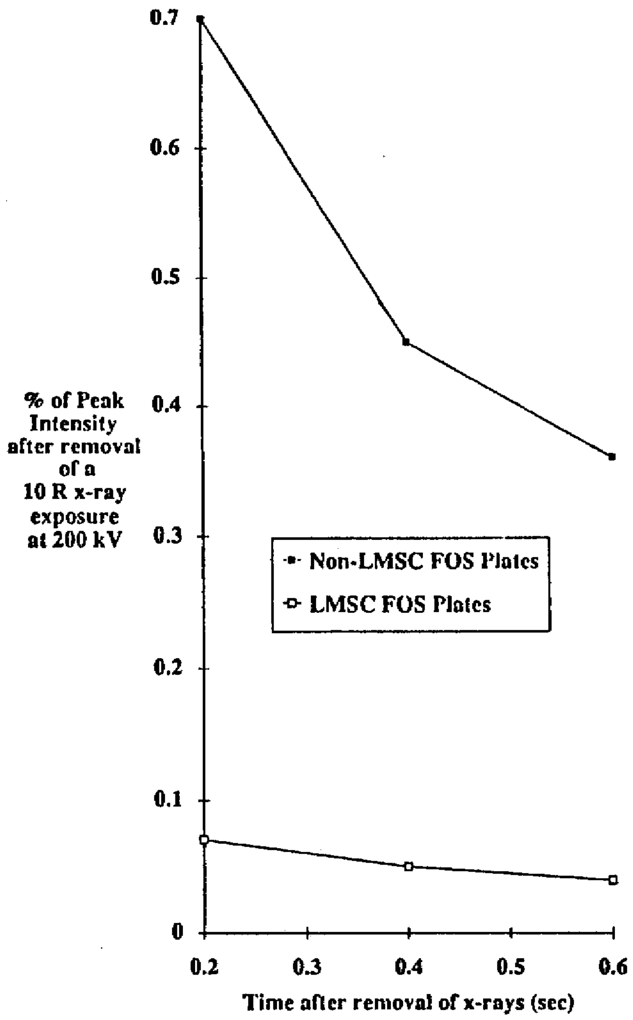


Fig. 3. Afterglow of FOS detectors.



Another major advantage of using glass scintillators is the ease of formability into plates, lenses and they can be easily drawn into fibers to produce fiber optic scintillators (FOS). Recently, one of the LMSC glass compositions was developed into a fiber-optic scintillator (FOS). The glass was used as the core glass to fabricate bundles of 17 micron fibers, each fiber surrounded by a cladding glass. These bundles were then fused into the FOS face plates. Within each face plate, these core fibers fluoresce under x-rays and their brightness is proportional to the x-ray intensity absorbed. This channeled light provides a sharp optical image plane at the surface of the face plate. Thus, the FOS face plate is capable of displaying a very high resolution image of the x-ray attenuation pattern of an object and furthermore can be directly bonded to a CCD or fiber-optic coupling elements without the need for inefficient lens coupling. Furthermore, the FOS plates can be made substantially thick for optimum S/N and for shielding of the x-ray sensitive electronic elements aft in the system.

Collimated Holes, Inc. (CHI) was subcontracted to fabricate the FOS face plates using an LMSC glass composition. Experiments performed on the LMSC FOS face plates demonstrated that the new devices have high spatial resolution and have significantly improved x-ray absorption efficiency, luminescence output, and afterglow/persistence characteristics compared to other FOS screens currently commercially available.
The absorption efficiency of the new FOS plates (0.5-in thick) was measured from 50-400 kV. The results are shown in Fig.1 compared to the absorption efficiency values of the other commercially available 0.5-in FOS plates and the highest spatial resolution polycrystalline phosphor materials. Figure 1 shows that as a function of increasing x-ray energy, the new FOS material provides improvement in x-ray absorption over the other high resolution detectors and that at 400 kV is nearly a factor of 6 more absorbing than the commercial high resolution phosphor screen technology.

The improved absorption efficiency of these new materials is partly responsible for the improved light output of these materials over previous technology FOS face plates at energies above ~100 kV. Results that compare the light output of the new technology and the commercial plates between 100 and 400 kV are shown in Fig. 2. All materials emit with similar green Tb(3+) emission spectra and are easily compared with a photopic setting on a photometer . Included in this chart is the light output for a standard commercially available high resolution phosphor screen. The new FOS face plates are as much as 160% more luminescent than the high resolution polycrystalline phosphor screen.

In an electronic imaging system, there should be no residual afterglow from the x-ray screen after the x-rays are removed or image smearing will result during the readout process. This is a severe problem with the pre-existing commercially available FOS detector technology which can have afterglow as high as 5 to 10% of peak intensity, 0.5 s after irradiation is halted. The new FOS face plates were specifically designed to reduce the trapping centers that create the afterglow.

The afterglow of the new FOS detectors was measured and compared to commercial scintillators using a sequence of 0.2 sec CCD exposures (yielding a 5 frame/sec frame rate) after removal of x-rays. Figure 3 shows that the pre-existing commercial plates have a persistence/afterglow problem with levels an order of magnitude higher than the new LMSC FOS material after removal of the x-rays. The new FOS face plates are approximately 0.1% of the peak intensity at 0.2 sec after removal of x-rays. Therefore, no image degradation is expected from the new FOS face plates due to residual images stored in the FOS.