Optical switching materials for space environments

Abhijit Sarkar, Salma Rahman, and George Rayfield

A novel optical-power limiter shows promise for use under intense irradiation.

Optical-power limiters (OPLs) are materials or devices designed to allow normal transmission of light at low intensities and limited transmission at higher irradiance (see Figure 1). Current increased levels of interest in OPLs for use in space are driven by the increasing number of space-based missions and applications that require laser protection. Polymeric-material-based OPL filters may experience degraded performance of their optical, nonlinear optical, and mechanical properties when exposed to the space environment for extended periods of time. Damage can be caused by solar UV radiation, solar-flare x-rays, electron and proton radiation, atomic oxygen (for low-Earth-orbit missions), and extreme temperature variations.

Temperature- and radiation-induced effects in optical and electronic components are well-known and can cause disruption in OPL functions or even sensor failure. Therefore, there is increased interest in developing materials that can withstand the space environment. Some of the best-performing OPLs contain multiple chromophores, such as fullerene and stilbenes. However, such materials are difficult to prepare, and are also affected by stability problems.

OPL devices rely on one or more nonlinear optical mechanisms, such as reverse saturable or multiphoton absorption, induced scattering, and photorefractivity. These processes have been studied extensively for OPL applications using a variety of materials. To date, however, none of the commonly used OPL materials, taken on their own, can provide the requisite ideal, smooth attenuation of an output beam. Therefore, design and development of new OPL-material types is needed. Some promising attempts have been made on the basis of combinations of nonlinear optical materials in cascading geometries using, for instance, multiple plate or tandem cells, or two intermediate focal planes in a sighting system. These efforts have led to encouraging initial results but much more work is still needed.

Figure 1. (a) Optical-power limiter (OPL), concept. (b) Output power ($E_o$) as a function of input energy ($E_{in}$) for an ideal OPL.

To qualify novel polymer-based OPL filters for long-term space use, all environmental aspects must be considered. The ideal test would simulate all effects to the same level of acceleration in the same facility, yet it could not perfectly replicate all aspects of space. The best alternative approach is sequential testing. Exposure to single environmental conditions is useful for
screening, and it can be used to determine the role of individual environments in OPL-filter performance degradation.

We have developed a novel OPL filter based on multi-component chromophores\textsuperscript{11–13} associated with hyperbranched polymers (HBPs),\textsuperscript{14} a class of dendritic nanoscale polymers that are highly branched and have a relatively large number of end groups.\textsuperscript{15} Cross-linkable end groups are particularly useful because they enable formation of networks in which HBPs of any mixture of chemical compositions can be combined to form honeycomb-like nanostructures. These nanodomains allow HBP networks to encapsulate smaller molecular-weight species within their highly branched nanoscopic molecular architecture (the ‘golf ball in the bush’ effect). We evaluated these filters in a high-radiation environment, focusing our experimental setup on the effects caused by gamma-ray radiation.\textsuperscript{13} The results provided promising evidence that our HBP-based OPL films are not adversely affected by gamma irradiation.

Our newly developed optical switching material is based on multimechanistic optical limiting. The HBP is uniquely suited for operation as solid matrix material with excellent optical quality. We built an OPL system using HBP as polymer matrix and a nonlinear scattering component in addition to other OPL-active components such as reverse-saturable absorber and photochromic dye (azo dye). We evaluated the samples’ OPL properties before and after gamma irradiation. Its effect on the glass substrate was obvious from the change in percentage transmission at 532nm: the post-irradiated glass surface is darker and therefore less transmissive. Our results for a representative sample are shown in Figure 2, based on irradiation with a 532nm laser. For this sample, the OPL onset occurred at an input energy of approximately 3\(\mu\)J, for an output clamping energy level of \(\sim 3.5\mu\)J. The post-irradiated OPL films can withstand fairly high doses of gamma-ray irradiation, and their OPL properties did not show any detrimental effects.

When appropriately combined in a HBP matrix, organic and inorganic chromophores offer a huge potential as OPL materials for sensor protection, and are promising candidates for space-based applications. The plasticity and flexibility of various host materials should allow us to design and fabricate a range of optimized structures to meet different requirements. As our next step we will evaluate the performance of such films exposed to other types of radiation present in space environments.

Author Information

Abhijit Sarkar
Michigan Molecular Institute
Midland, MI
and
Oxazogen Inc.
Midland, MI

Abhijit Sarkar received his PhD in organic chemistry from the Indian Institute of Technology in 1993. He is a research scientist whose areas of interest include design and preparation of organic molecules for nonlinear optical materials as well as design and development of photonic devices. He has authored over fifty refereed papers and has four patents.

Salma Rahman
Michigan Molecular Institute
Midland, MI

Salma Rahman received her PhD from Iowa State University in 2005. She is an associate scientist with interests in bioanalytical techniques and instrumentation, membrane design and development, photonics, and development of OPL materials.

George Rayfield
Department of Physics
University of Oregon
Eugene, OR
and
Aquarious Inc.
Las Vegas, NV

Continued on next page
George Rayfield received his PhD in physics from the University of California at Berkeley in 1964. He is currently emeritus professor of physics and founder of Aquarious Inc., a photonics startup company. His areas of expertise include solid-state physics, low-temperature physics, biophysics, and development of bacteriorhodopsin materials for photonic applications.

References

© 2009 SPIE