Nanotechnology Based Optical Power Control Devices

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ABSTRACT

Near-field interactions in artificial nanostructured materials can provide a variety of functionalities useful for optical systems integration. We are taking advantage of the unique capabilities of nanoparticles guest embedded within dielectric host matrices for field enhancement effect in developing next generation of non-linear components and devices to passively control and regulate optical power.

We report on passive optical power control devices based on a range of photonic nanostructures, including mainly nanostructures for spatial field localization to enhance optical nonlinearities.

Keywords: nanotechnology, optical power control, limiting, blocking, protection filter

1 INTRODUCTION

The design of artificial nanostructured materials for the use in non-linear devices and integrated photonic systems is very challenging as it involves nanoparticles, nanomaterials and quantum physics equations. Near-field interactions in artificial nanostructured materials can provide a variety of functionalities useful for optical systems integration. For example, nanoparticles embedded within a dielectric host are known to have a field enhancement effect and therefore lower the threshold of laser induced damage [1]. Optical limiting effects are observed in is carbon suspensions and reverse saturable absorbers [2]. Here, we take advantage of the unique field enhancement capabilities of nanoparticles guest embedded within dielectric host matrices.

We report on passive optical power control devices, mainly based on nanostructures for spatial field localization to enhance optical nonlinearities. We present two main optical power control mechanisms: blocking and limiting (sections 2.1 and 2.2), as well as their corresponding nano-scale phenomena. Section 3 presents three novel generic optical power control components: fiber optical fuse [3], optical power limiter [4] and free-space wideband protection filter [5] (section). Finally, section 4 presents future applications such as optical power regulating for cameras, windows and car rearview mirrors are discussed.

2 OPTICAL POWER CONTROL MECHANISMS

We developed two main optical power control mechanisms: blocking and limiting. In the following we discuss the two and their nanostructures based origin.

2.1 Blocking Mechanism

Our blocking mechanism (Figure 1) is enabled by catastrophic breakdown of the material when an over-power event occurs. It is performed by novel nanostructures that are used as threshold trigger at relatively low powers according to the nanoparticles and nanostructure design. The catastrophic breakdown effect occurs at the interfaces between metallic and non-metallic layers in the optical path. These layers are nearly transparent at low input powers. However, the catastrophic breakdown results in significantly enhanced scattering from the layers interface, leading to significant decrease in transmission. This effect is irreversible, similarly to electrical fuses.

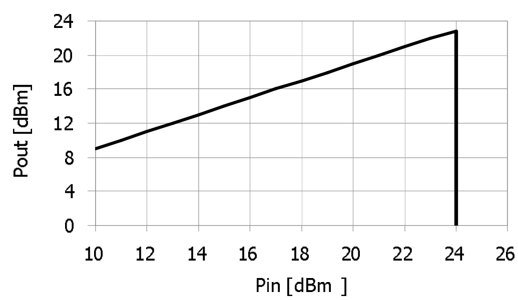

Figure 1: Optical power blocking effect – interruption of optical transmittance by catastrophic breakdown. Based on nano-structures that are used as threshold triggered switches

The base materials for this mechanism can be thin layers of only few nanometers size of a certain metal such as gold, in contact with a dielectric layer such as silica, to achieve the required interface. The desired breakdown threshold is then tuned according to the metal thickness, structure and the metal-dielectric interface nature [6]. We can lower threshold powers down to few tens of mW by taking the advantage of the field enhancement effect of special nanostructures and unique combinations of guest-host pairs.

2.2 Limiting Mechanism

The limiting of optical transmittance (Figure 2) is done mainly by non-linear absorption-induced scattering. At low input powers, the limiter is transparent, whereas at high input powers the limiter lets through only a certain power.

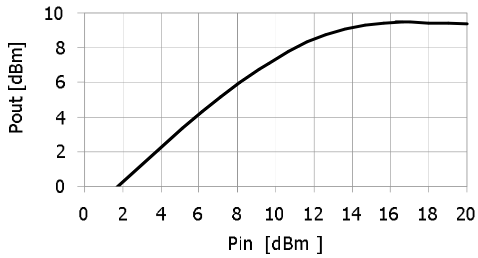

Figure 2: Optical power limiting effect – limiting of optical transmittance based on novel nano-structures that are used as non-linear scattering medium

The scattering method is based on novel nanostructures and nano-particles inserted in the optical path and are used as the non-linear scattering medium. At low powers, there is only a residual absorption effect (no scattering), which results in relatively small optical transmission loss. However, scattering becomes significant at high input powers, and allows only a fraction of the input power to propagate (see Figure 3).

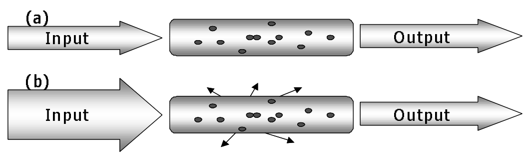

Figure 3: Limiting mechanism: (a) at low input power, only slight attenuation due to absorption; (b) at high input power, large attenuation due to strong scattering induced by the nano-particles.

3 PASSIVE OPTICAL POWER CONTROL DEVICES

Passive optical power control is typically based on nonlinear optical processes. In general, such processes can be nonlinear-scattering, absorption or reflection. As reflections are not desired in optical networks, and absorption may be problematic at high input power, nonlinear-scattering is probably the preferred method.

Here we present three devices based on the blocking and limiting mechanisms discussed earlier. The first two, the optical fuse and the optical limiter, are fiber-based devices for the Telecom market, protecting and controlling optical power within networks. Whereas the third is a free space passive optical filter suitable for eye and sensors protection from high power laser pulses.

3.1 Optical Fuse

An optical fuse is an inline component (see Figure 4) that is transparent under low power operation, but becomes permanently opaque when the input power reaches the threshold level. The optical fuse is based on the blocking mechanism as shown in Figure 1. As the fuse action is irreversible, optical fuses are designed to operate at emergency cases, such as in networks that are susceptible to undesirable power spikes that arise from amplifiers or external sources that are multiplexed into them.

Figure 4: Optical Fuse; in-line device version

In order to measure the fuse response time under different power levels, we developed a custom setup (namely, a programmable optical pulse generator), for creating pulses of different lengths, powers and shapes. Various pulses were input to the optical fuse in order to examine its response. Figure 5 shows an example, where the input is a high power pulse (black). As evident, the output pulse (gray) is blocked after the input pulse exceeds a certain power. Here, the response time is shorter than 10 microseconds.

The response time decreases with the input power. Typically, the response time for powers slightly higher (a few dBs) than the threshold power is few tens of microseconds, whereas for stronger pulses (significantly higher than the threshold power), response times as low as a few nanoseconds were measured.

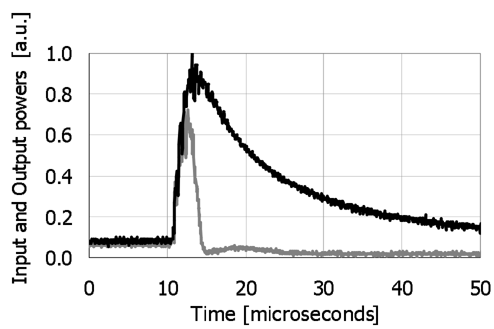

Figure 5: Response time of the optical fuse; input pulse (black) and output pulse (gray). As evident, the response time in this case is less than 10 microseconds

3.2 Optical Power Limiter

The main function of the optical power limiter is limiting the output power to a certain level (e.g., the limit-power). At low input powers, the limiter is transparent, whereas at input powers higher than the limit-power, the output power is nearly constant. Also, as opposed to the optical fuse, the optical limiting is reversible; meaning that when the input power drops back, the optical power limiter becomes transparent again. Figure 6 shows an experimental plot of the output power as a function of the input power. Here, the insertion loss at low power is ~2dB, whereas the limit power is ~7dBm. The maximum CW input power is around 14dBm. Note also that the graph describes a few power cycles, confirming the reversibility of the power limiting operation.

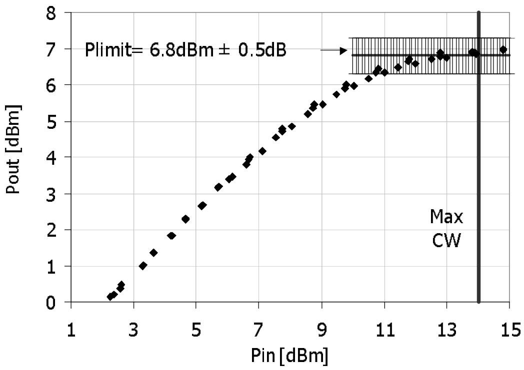

Figure 6: Output power vs. input power cycles as recorded for an of approximately 7dBm optical power limiter

Another important property of the optical power limiter is the response time. Fast response is required in order to block the excess power. However, as opposed to the optical fuse where immediate blocking is required, the response of the optical limiter should be slower than the data rate, in order not to affect the transmitted data.

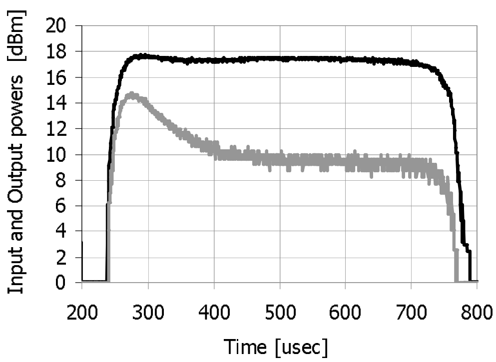

Figure 7: Input pulse (black) and output power (gray) as a function of time. The response time derived from the graph is <200μsec

Figure 7 presents a measurement of the optical power limiter response time. Here, the input power rises beyond the limit power. First, the output power follows the input power, but stabilizes at the limit power afterwards. The response time is derived from the size of the "hump".

3.3 Wideband Protection Filter (WPF)

The WPF is a totally passive component, designed to protect against excessive optical power transmission. As opposed to the Limiter and Fuse that are fiber-based components, the WPF is a free space device suited for imaging and detection applications such as sensors, cameras and the human eye protection. The WPF is solid-state, and is composed of an active layer sandwiched between two parallel optical windows. Figure 8 presents a photo of two WPF samples; these samples are 1" in diameter, and their optical quality is similar to that of typical 1" optical windows.

Figure 8: Wideband Protection Filter components

The WPF is also based on the blocking mechanism as discussed in section 2.1. The basic non-linear phenomenon that occurs when the WPF is hit by high power laser light is catastrophic breakdown. The active layer of the WPF consists of nano-particles and clusters that enhance the effect of high electro-magnetic fields, leading to a strong breakdown effect under high optical power density. The catastrophic breakdown results in enhanced scattering from the active layer, leading to significant decrease in transmission. That spot of decreased transmission in the WPF becomes permanently opaque and remain as so for long exposures to high power laser light. In order to obtain the optical power density required for the breakdown effect, the WPF should generally be placed at or near the focus of the system (see Figure 9).

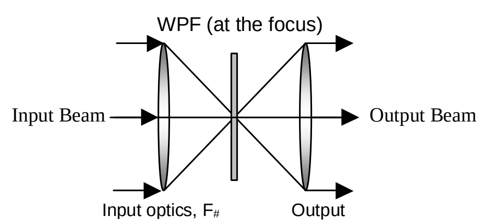

Figure 9: Schematic, cross-sectional view of a WPF within an optical system

The WPF reacts to both continuous and pulsed damaging lasers. The reaction of the WPF is fast, so the switch-off is fast enough to intercept damaging optical power before damage occurs, as it can easily operate in the nanosecond range. Protection is both wavelength- and impingement angle independent, so the same WPF can block various lasers from various directions. Also, as the WPF is generally placed at or near the focus, most of the field of view remains transparent even after operation of the WPF; the opaque spots are local and limited to the spots exposed to the high power. These spots remain opaque for all wavelengths for long exposures to high power light.

Blocking efficiency is more than two to three orders of magnitude. Also, the opaque spot generally scatters the light of impinging beams, so the small residual transmitted beam through this spot is quality-degraded.

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3.4 Applications and Discussion

We presented several optical power control devices: Optical Fuse, Optical Limiter and Wideband Protection Filter. The first two can regulate and control the optical power in telecommunication networks by either replacing or complementing existing power feedback control loops, as another layer to the electronic layer.

The optical power limiter serves either as a protection device or as a power-regulating device. Whereas the optical fuse is designed mostly for protection purposes. As a power-regulating device, the optical power limiter can serve as a gain- or power-equalizer, or for reducing power fluctuations ("noise eater"). As protection devices, both the optical limiter (at lower power levels) and the optical fuse (at higher power levels), can protect detectors or receivers from over-power and even increase the system's dynamic range; The optical fuse can also serve as a laser safety device and even as prevention of catastrophic damage due to effects such as the fiber-fuse phenomenon [7], [8].

The WPF is designed to protect imaging and detection systems that are susceptible to detector saturation or permanent damage caused by powerful light sources or high power lasers in the free space configuration.

4 FUTURE APPLICATIONS

The need of optical power control and regulation implies not only to sophisticated communication systems but also to everyday cameras and even to a common car rear-view mirror. Regulating optical power levels within various systems, such as cameras, requires today an electronic feedback control or after data processing, which introduce complex and expensive systems.

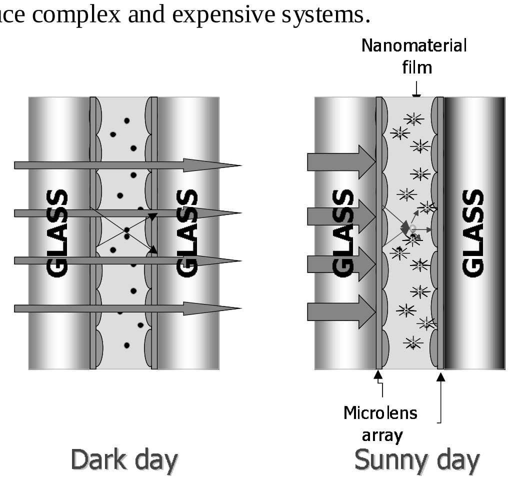

Figure 10: Dynamic Sunlight Filter illustration

Our next generation of optical power control technology is the Dynamic Sunlight Filter (DSF). DSF technology will enable users to control the amount of light passing the element in a passive way. The DSF element will automatically vary its transparency according to the amount of incident light.

The DSF is based on the limiting power control mechanism (refer to section 2.2). In the natural state, when incident light is below a predefined level the DSF is highly transparent, so light just passes through (Figure 10). When light intensity increases, such as in the case of sunrise or when a glare from approaching headlights is facing your car rear-mirror, the DSF transmission decreases according to the intensity of the incident light, resulting in a darkened state. The darkening effect is limited only to the over exposed area. The area becomes transparent again, once the light intensity is reduced below the required level.

The same effect of automatically transparency decreasing within the glared area can be applicable to multiple applications such as cameras, rear-view mirrors, windows, sunglasses and many others. This exciting, cutting-edge technology may allow consumers to benefit a cooling room in a sunny day by an automated window darken itself to the predefined light amount to pass through.

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