Passive Light Power Control Enabled by Nanotechnology

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ABSTRACT

The need to regulate and control light power is relevant not only for sophisticated communication systems but also to everyday optical equipment such as consumer point-and-shoot cameras or even a common car rear-view mirror. We explore the unique capabilities and advantages of nanotechnology in developing next generation non-linear components and devices to control and regulate optical power in a passive way.

We report on passive optical power control devices based on a range of photonic nanostructures. We present the optical fuse, limiter and our next generation solution the Dynamic Sunlight Filter (DSF).

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

1 INTRODUCTION

The need to regulate and control light power is relevant not only for sophisticated communication systems but also to everyday optical equipment such as consumer point-and-shoot cameras or even a common car rear-view mirror. Regulating optical power levels within various systems, such as cameras, requires today an electronic feedback control or offline data processing, which introduces complex and expensive systems. We explore the unique capabilities and advantages of nanotechnology in developing next generation non-linear components and devices to control and regulate optical power in a passive way.

The design of artificial nanostructured materials for the use in non-linear devices and integrated photonic systems is very challenging as it involves the need to incorporate the 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 within the material [1,2]. Another example for limiting effect is carbon suspensions and reverse saturable absorber materials [3]. 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. Based on our nanotechnology we developed a whole family of Optical Power Control (OPC) components and solutions [4, 5, 6].

We report on our next generation solution, the Dynamic Sunlight Filter (DSF), which is based on our fundamental principles of nanotechnology and nanostructure optics dedicated for sunlight applications. In the normal state, when incident light is below a predefined level the DSF is highly transparent, light just passes through it. As the light level is increased and gets more intense, such as in the case of morning sun, or the headlights of an approaching car facing the rear-view mirror, the DSF transmission decreases accordingly, eventually reaching a darkened state. The darkening effect is selective and is limited only to the intense light areas in the image. This process is reversible and the filter returns to its transparent state once the intensity of light decreases to its normal level.

We present our nanotechnology power control mechanisms as well as a preliminary design of the DSF. We demonstrate power control and regulation in prototype configuration for several device approaches. Finally, we discuss DSF possible applications, our wish list includes, among others, enjoying a cooler room in a sunny summer day by automatically darkening the window to a predefined level, thus passing less heat and resulting in energy saving.

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. We present the two main optical power control mechanisms: blocking (section 2.1) and limiting (section 2.3), as well as their corresponding nano-scale phenomena. We present device examples of two novel generic optical power control components: fiber optical fuse [7] (section 2.2) and fiber optical limiter [8] (section 2.4). A third one of free-space wideband protection filter is discussed elsewhere [9]. We present also preliminary design for future applications such as optical power regulating of sunlight (DSF) and its possible applications (section 3).

2 OPTICAL POWER CONTROL MECHANISM AND DEVICE EXAMPLES

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

2.1 Blocking Mechanism Principles

Our blocking mechanism (Figure 1) is enabled by catastrophic breakdown of the material when over power 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 optical blocking mechanism is based on a catastrophic breakdown effect, which 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 catastrophic breakdown is irreversible in similar way to electrical fuse.

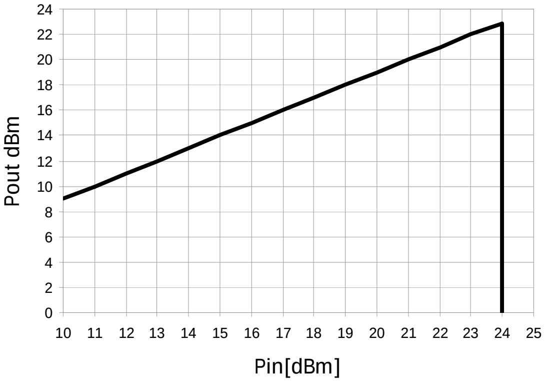


Figure 1: Optical power blocking effect – interruption of optical transmittance by catastrophic breakdown. Based on novel nano-structures that are used as threshold triggered switches

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 [10]. When embedded guest nanoparticles within a host dielectric material, we can simplify the fabrication technique. 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 Blocking Mechanism for the Optical Fuse

An optical fuse is an inline component 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 networks that are susceptible to undesirable power spikes that arise from amplifiers or external sources that are multiplexed into them.

Figure 2: Optical Fuse In-line device version

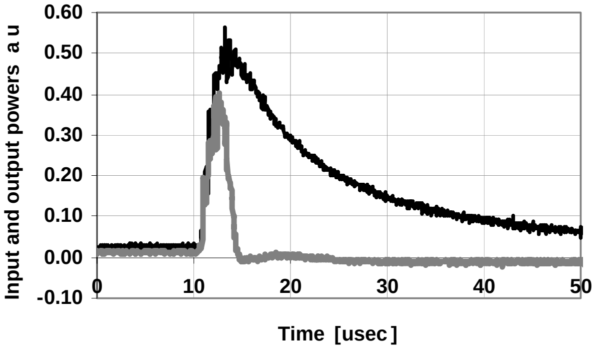


Figure 3: Response time of the optical fuse. The input pulse is depicted in black whereas the output pulse is depicted in gray. As evident, the response time in this case is less than 10 microseconds

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 3 shows an example, where the input is a high power pulse, marked in 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.

2.3 Limiting Mechanism Principles

The limiting of optical transmittance (Figure 4) is done mainly by non-linear absorption-induced scattering. 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 5).

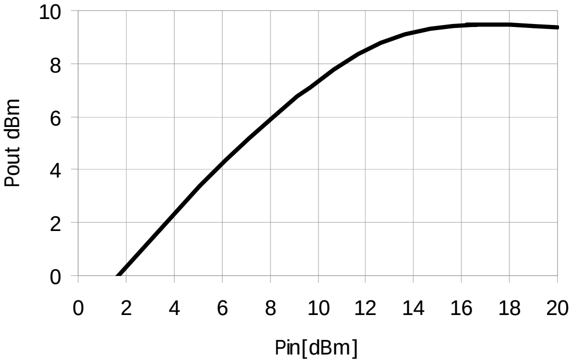


Figure 4: Optical power limiting effect - limiting of optical transmittance mainly by non-linear scattering. Based on novel nano-structures that are used as non-linear scattering medium

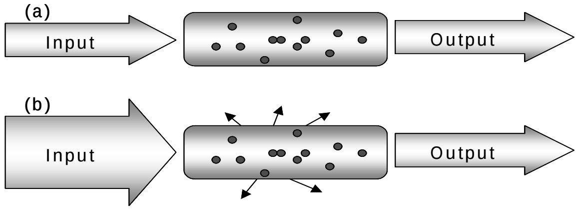


Figure 5: Limiting mechanism: (a) at low input power, only slight attenuation in output power due to absorption. (b) at high input power, large attenuation due to strong scattering induced by the nano-particles.

2.4 Optical Limiter: device example for limiting mechanism

The optical power limiters main function is limiting the output power to a certain level (namely, the limit-power). At low input powers, the limiter is transparent, whereas at input powers higher than the limit-power, the output power is constant. Also, as opposed to the optical fuse, the action of the optical power limiter is reversible; meaning that when the input power drops back, the optical power limiter becomes transparent again. Figure 4 shows an experimental plot of the output power as a function of the input power. Here, the insertion loss at low power is approximately 2dB, whereas the limit power is approximately 7dBm. The maximum CW input power defined is around 14dBm. Note also that the graph describes a few power cycles, confirming the reversibility of the power limiting operation.

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 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"..

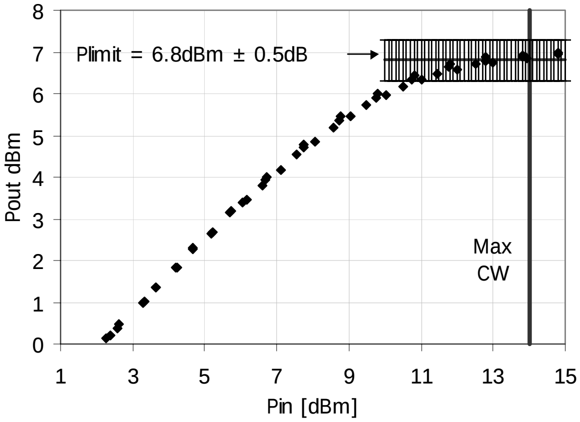


Figure 6: Output power vs. input power cycles as recorded for an of approximately 7dBm optical power limiter

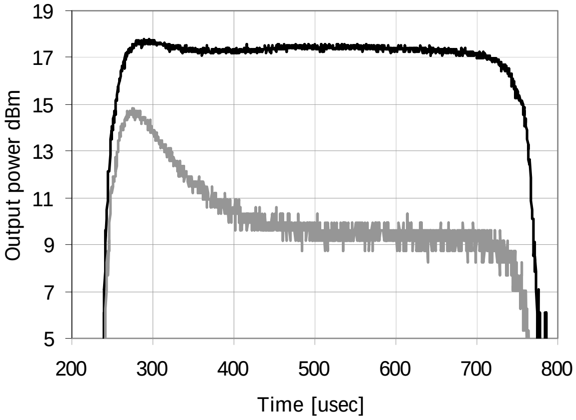


Figure 7: Input pulse (black) and output power (gray) as a function of time. The response time derived from the graph is ~200µsec

2.5 Discussion

We presented several optical power control devices examples: Optical Fuse, Optical Limiter and Wideband Protection Filter. In general, optical power fuses and limiters can regulate and control the optical power in telecommunication networks. They can either replace or complement 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, either the optical limiter (at lower power levels) and/or optical fuse (at higher power levels), it can protect detectors or receivers from over-power and even increase the system’s dynamic range; The optical fuse can serve also as a laser safety device and even as prevention of catastrophic damage due to effects such as the fiber-fuse phenomenon [11], [12].

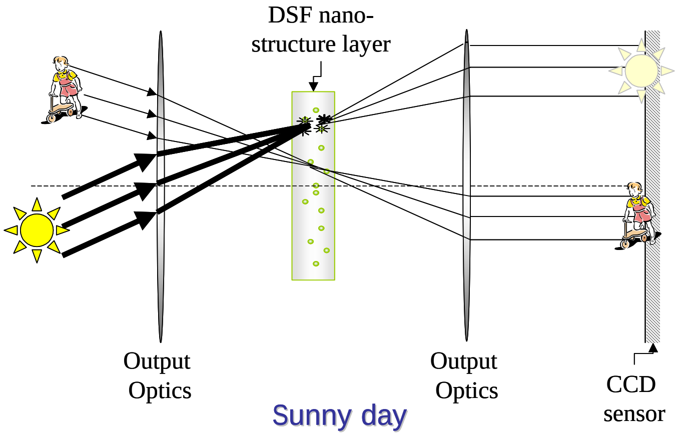
Another example of blocking mechanism based device is the Wideband Protection Filter (WPF), which is designed to protect imaging and detection systems that are susceptible to detector saturation or permanent damage caused by powerful light sources or high power lasers in the free space configuration. The WPF is described elsewhere [9].

3 DYNAMIC SUNLIGHT FILTER (DSF)

The need of optical power controlling and regulating implies not only to sophisticate 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.

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.

Dynamic Sunlight Filter (DSF) is designed by principles of nanotechnology and nanostructure optics similar to what discussed for our limiting power control mechanism (refer to section 2.3). In the natural state, when incident light is below a predefined level the DSF is highly transparent, so light just pass through (Figure 8). When light increases continuously, 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 amount of the incident lights, resulting in a darkened state. The darkening effect is limited only to the over exposed area. The area becomes transparent again, once the amount of light reduces below the required level.



The same effect of automatically transparency decreasing within the glared area is applicable to multiple applications such as cameras, rear-view mirrors, windows, sunglasses and many other. This exciting, cutting-edge technology will 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.

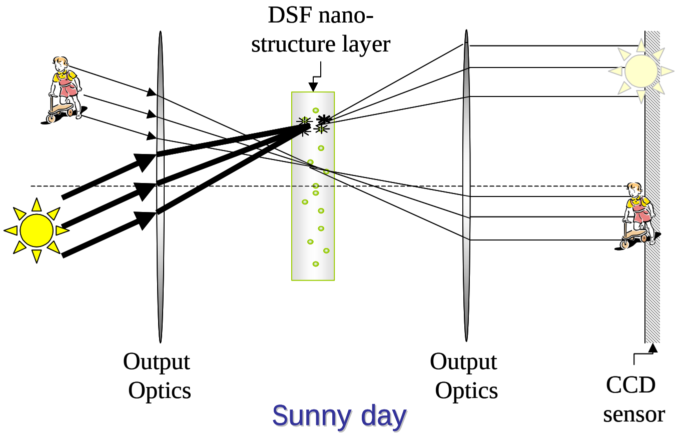


Figure 8: Dynamic Sunlight Filter illustration

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