Optical limiter using epsilon-near-zero grating

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***Abstract*—Fast optical limiters are needed to protect sensors from intense short laser pulses. An optical limiter design based on a conducting-oxide grating with a large nonlinear refractive index at the plasma frequency is proposed and investigated.**

***Index Terms*—optical limiter, epsilon near zero, metasurface, FTO**

I. INTRODUCTION

An optical limiter is a device designed to keep the power transmitted by an optical system below some specified maximum value. It must do this while maintaining high transmittance at low input powers. The most important application of such a device is the protection of sensitive optical sensors and components from laser damage [1].

It has recently been reported by several authors [2], including members of our team [3] [4], that Indium Tin Oxide (ITO) exhibits a very large nonlinear refractive index at wavelengths close to the zero crossing of the real part of the permittivity. Since the complex index n is the square root of the complex permittivity ε, $\Delta n = \Delta\varepsilon/2\sqrt{\varepsilon}$, which becomes large when ε becomes small in the Epsilon Near Zero (ENZ) spectral region.

Fluorine-doped tin oxide, or $F : SnO_2$ (FTO) is another conductive oxide with an ENZ wavelength controlled by the concentration of fluorine in the aqueous starting solution. Its ENZ wavelength has a demonstrated controllable range of from 1.9 to 14.2 μm, or near- through long-wave-IR. For certain applications conformal coating of large areas is desired, this is difficult to accomplish with ITO since the method of deposit is sputtering. FTO is strongly adhesive and is stable up to very high temperatures. Deposition can be done by aqueous spray, which requires no vacuum, so that arbitrarily large surfaces can be coated at low cost, facilitating mass production.

In this work a thin transparent film patterned in the form of a grating of alternating stripes made of active FTO and a passive index matching material is presented.

Figure 1 shows the device operation, briefly, When low intensity light falls on the grating there is no deflection of the beam since the indices of all stripes are the same. At high intensity, an index grating is formed due to the strong increase in the refractive index of FTO at ENZ, so that high intensity beams are strongly diffracted away from the sensor.

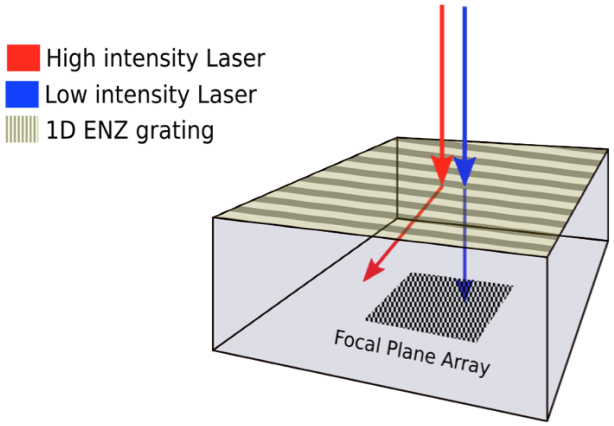

Fig. 1. ENZ grating under high and low intensity illumination conditions.

II. METHOD

In this work a grating formed by stripes of FTO and metal-black as passive index matching material is numerically analyzed. Metal black can be deposited as nano-structured low-density films produced by thermal evaporation in a bad vacuum.

Figure 2(a) presents the ENZ index as a function of λ_{ENZ} for differently doped FTO samples using permittivity data in [5]. Index values range between 1 and 2 for the complete range of λ_{ENZ}. The variation is linear in λ_{ENZ} according to Eq. (1).

$$n_{ENZ} = k_{ENZ} = 0.089\lambda_{ENZ} + 0.82 \qquad (1)$$

Figure 2(b) shows the real and imaginary parts of the complex index as a function of ϵ''. The n and k approach each other as desired with increasing ϵ''. The average of n and k is indicated by the green smooth line.

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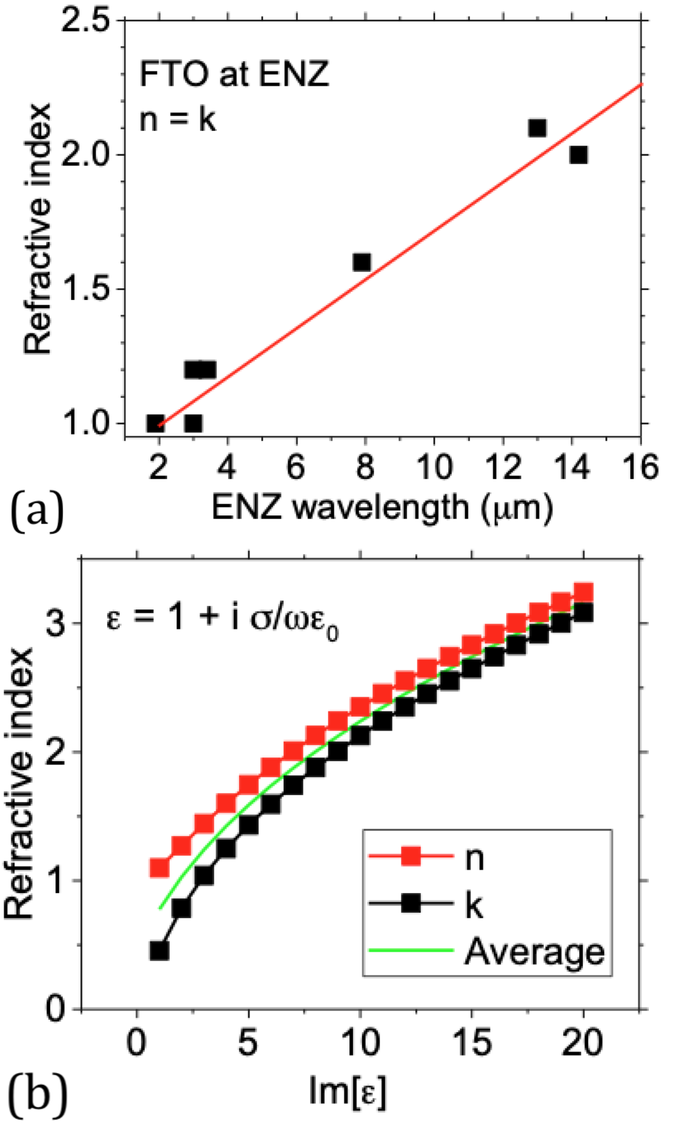

Fig. 2. (a) Refractive index of FTO as a function of ENZ wavelength. (b) Complex refractive index of a poor conductor as a function of $\epsilon'' = \sigma/\omega\epsilon_0$.

Transmittance and optical limiting characteristics for the ENZ grating are calculated by numerical simulations using COMSOL Multiphysics. Briefly the Maxwell equations were solved by the Finite Element Method, in the simulations the experimentally obtained linear and nonlinear optical properties of the materials were included.

A linearly polarized plane wave simulating the incident electromagnetic wave was launched at the surface of the ENZ grating, and the transmitted and reflected waves were calculated as a function of incident angle, wavelength, and intensity.

III. RESULTS

Figure 3(a) shows a COMSOL simulation of a grating, similar to the one shown in Figure 1, with n=1 and n=3 for the low and high intensity field, in this case no losses were considered. The simulations were performed with a grating constant of 2.1 μm and an incident wavelength of 2.2 μm.

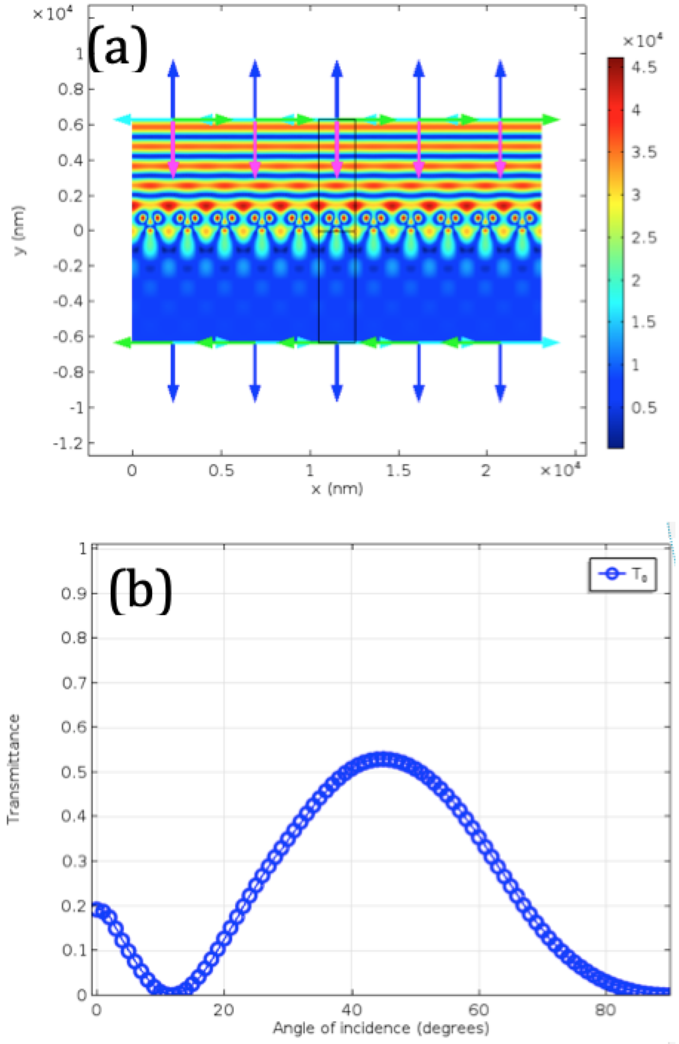

Fig. 3. (a) E-field through a 1D ENZ grating due to a high intensity E-field at normal incidence (b) Transmission of the high intensity E-field through the 1D ENZ grating as a function of angle of incidence.

IV. CONCLUSIONS

Numerical simulation results show that for the designed ENZ grating the transmission is reduced to 20% at normal incidence and to almost 0% at 12 degree incidence (Fig. 3(b)). These results confirm the possibility of using a 1D ENZ grating for effective optical limiting.

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