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SHORT COMMUNICATIONS

OPTICAL LIMITING IN FREE-STANDING POROUS SILICON FILMS

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1. Introduction

The constant interest in porous silicon (PS) in the past years has been connected with the potential applications of this material in silicon based optoelectronics. Assuming quantum confinement effect and the possibility of the optical bandgap control, PS becomes very attractive material for visible silicon optoelectronic devices, including active ones.

The nonlinear light transmission in PS is studied in a large temporal range, but the most of the papers are dealing with millisecond [3] and picosecond/femtosecond [3-5] time scales. The ultrafast nonlinear phenomena are important for all-optical switchers, while the slow optical nonlinear effects are suggested for parallel operations [6]. Equally interesting are applications such as optical limiters or noise reduction [7]. In the present letter, we studied the optical power limiting during nonlinear optical propagation of strong laser pulses in free-standing PS films.

2. Experimental

The PS films (thickness d = 15 – 25 μm) were prepared by anodization from bulk commercial Si substrates (KES 0.01), 0.01 Ω·cm, (111) - cut orientation. An electrolyte HF (49%):ethanol, (1:1) was used. Anodization was carried out at room temperature in two chambers unit cell with 1 cm^2 surface area at current density j = 7 mA/cm^2 for about 20 min. Afterwards, for free-standing film separation the current density was switched sharply to j = 70 mA/cm^2. Free-standing PS films were rinsed by ethanol and dried in air stream. The used PS thin films are optically homogeneous.

Fig. 1 shows the optical absorption spectra for measured PS film with 0.16 μm thickness. No photoluminescence properties for these films under UV excitation are detected.

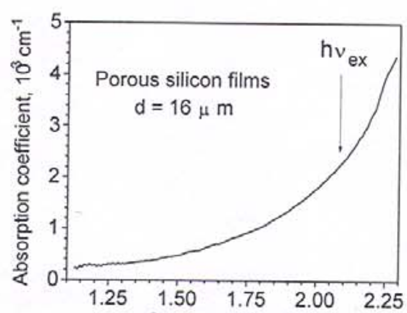

Fig. 1 Optical absorption spectra of free-standing PS film with 0.16 μm thickness. Arrow laser wavelength position.

The experiments were done in a single-beam transmission or reflection set-up, which has allowed to measure synchronously the fluences of incident (E_0), transmitted (E_t) or reflected (E_r) pulses. The measurements were carried out using a rhodamine 6G flash-lamp pumped dye laser ($h\nu_{ex}$ = 2.09 eV, pulse duration (FWHM) $\tau_{ex} \approx 0.9$ μs, bandwidth $\Delta\lambda_{ex} \approx 0.1$ nm). The wavelength of the dye laser generation was over the range of the strong light absorption of the material (where the absorption coefficient $\alpha \geq 2 \cdot 10^3$ cm^{-1}, Fig. 1). Both input and output/reflected laser pulses were registered by coaxial vacuum photodetectors (time resolution < 10^{-9} s) and an oscilloscope. The spot diameter of the focused on the sample laser beam was 0.2 - 0.3 mm and the input fluence up to 1 J/cm^2 was achieved. All experiments were done at room temperature.

3. Results and discussion

In Fig. 2 the transmitted through PS sample pulse fluence (E) as a function of the input one (E_o) is shown. At the input fluences higher than the threshold value $E_{th} \approx 0.08$ - 0.1 J/cm^2 a nonlinear increasing of the light absorption in PS was detected, i.e., utilising the nonlinear light absorption, the effect of optical limiting was demonstrated. PS film seems to work like a power limiter for strong laser pulses with a sublinear transmission function. The limiting function is clearly established by measurements: at $E_0 \sim 0.3$ J/cm^2 (near the saturation level) the PS film (with 16 μm thickness) transmission is reduced about to half of the linear transmission (Fig.2). The measured nonlinear absorption changes are reversible up to surface damage pulse fluence (~ 0.36 J/cm^2). Within experimental errors (~ 20 %) no residual effects are detected. This was tested by measurements performed with increasing and decreasing incident fluence on the same place of the sample.

In order to avoid the effect of the light fluence decreasing due to the photodetector size limitation (or induced light scattering) the vacuum photodetectors with large diameter of photocathode (~ 5.5 cm), situated no far from the sample, were used.

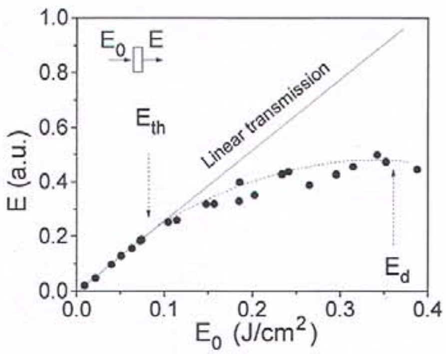

Fig. 2 Optical limiting in PS film. The sample has the thickness of 16 μm.

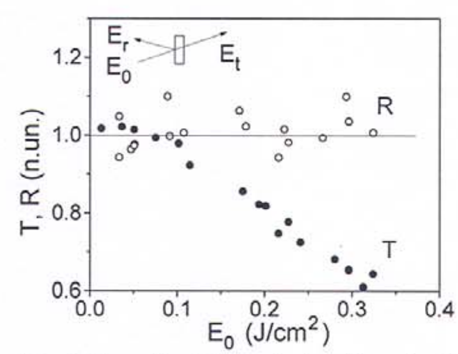

Fig. 3 Normalised transmission (T) and reflection (R) from the PS film vs. laser pulse input fluence. The beam incident angle ~ 20°.

The decrease of output laser fluence can be also conditioned by light reflection increasing, related to a carrier concentration increase in the exciting region, and by melting of the material on the surface of this region. To clarify this, the behaviour of the light reflected from the surface of the PS films in a regime of laser pulse nonlinear transmission was also measured. Fig. 3 shows the reflection and transmission of PS film of the normalized laser pulse energy versus laser input fluence. Up to ~ 0.3 J/cm^2 in the reflected light increasing is not detected. This points to a real increase of the PS light absorption.

The induced light absorption in PS films was investigated in [1, 3]. As a rule the slow response nonlinearity in PS is connected with the carrier localization on the surface states of Si microcrystals [1, 3]. Since PS has an extremely low thermal conductivity, the thermal effects due to laser heating may also play a significant role [1].

We suggest that the optical limiting arises from nonlinear photoinduced absorption of laser pulses in PS films. Analogous nonlinear photodarkening and optical hysteresis phenomena were measured in non-crystalline semiconductors (chalcogenide glass films As_2S_3, As_2Se_3, AsSe, $GeSe_2$, and a-Si:H films), which can be explained by the mechanism of nonlinear light absorption, taking into account the interaction with nonequilibrium phonons and localized vibrational modes [6,7]. This mechanism can be also applied in the case of PS, since this material possesses a large specific surface and, consequently, a large concentration of structural inhomogeneities of crystalline silicon at nanometric scale, that may lead to some spatial localization of the phonon vibrational modes and, as a result, to contribute to the formation of non-equilibrium state at a high level of laser excitation [6,7].

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