Photoreflectance spectroscopy of the mesoporous silicon structures

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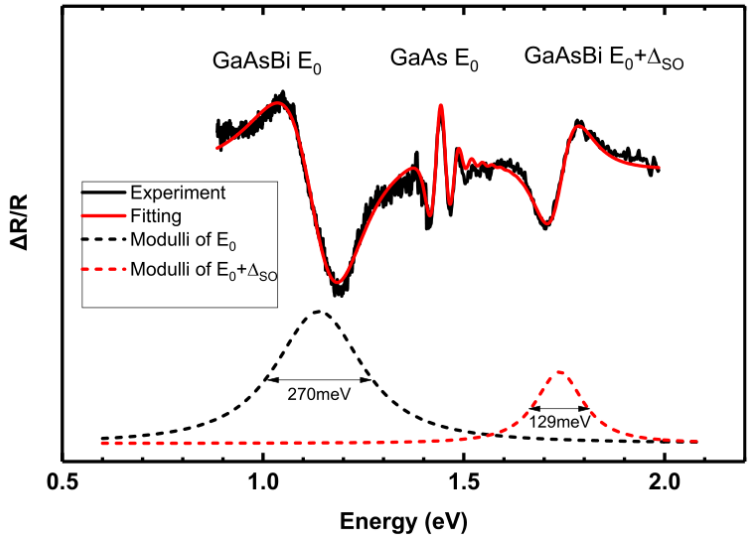
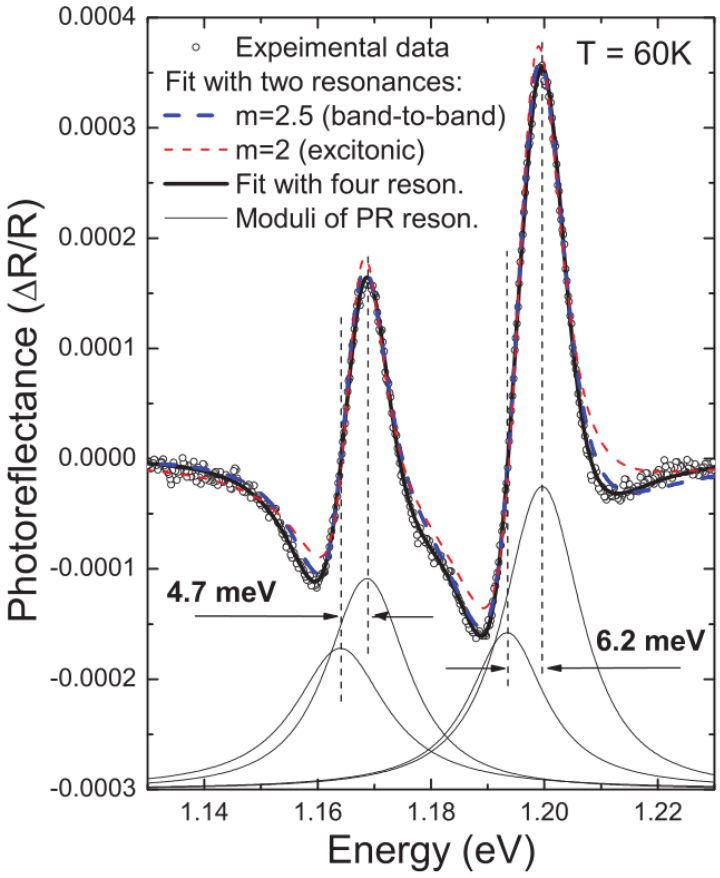
Photoreflectance

The photoreflectance spectroscopy is a non-destructive and sensitive technique to investigate properties of semiconductors and nonlinear materials.
The modulation of reflectance with external electric or optical field can reveal the inner structure of the sample

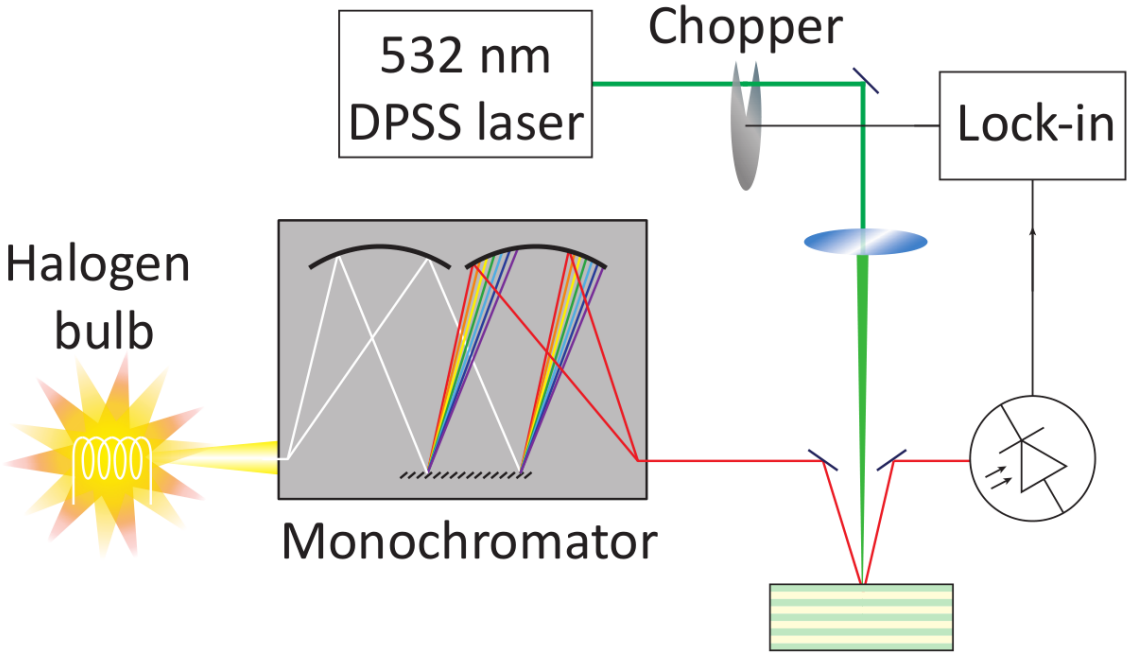


J. Appl. Phys. 123, 035702 (2018)



PRB 88, 125201 (2013)

Experimental setup

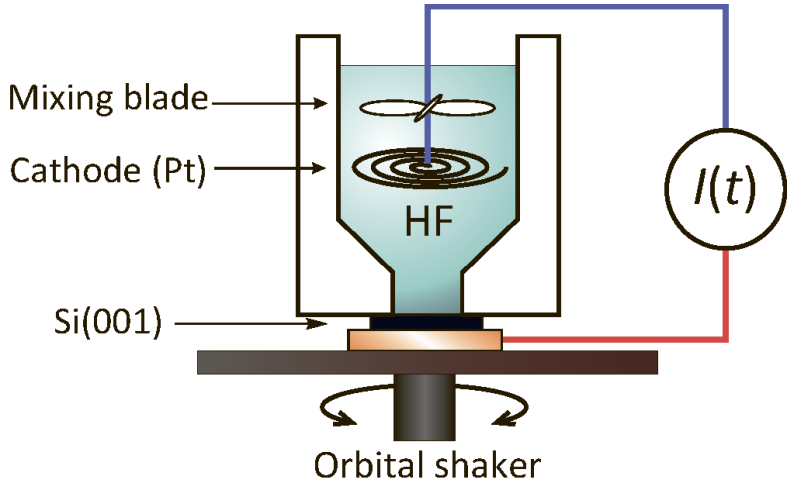


Measured signal:

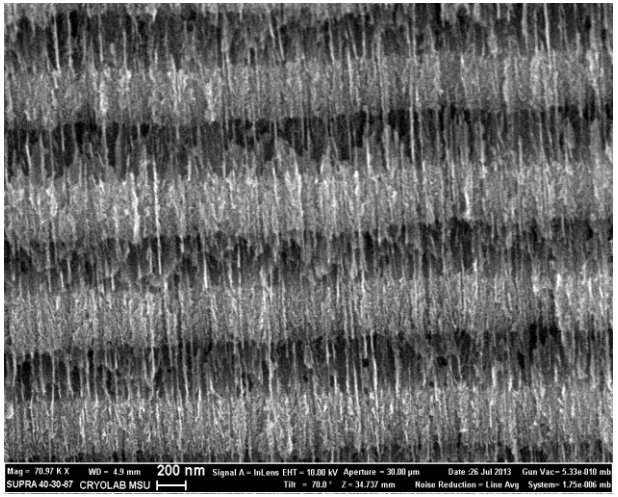
$$\frac{dR}{R} = \frac{R_{on} - R_{off}}{R_{off}}$$

The reflectance of the sample is measured by incoherent (probe) light. The reflectance signal Is modulated by a pulsed laser radiation (1-100 mW)

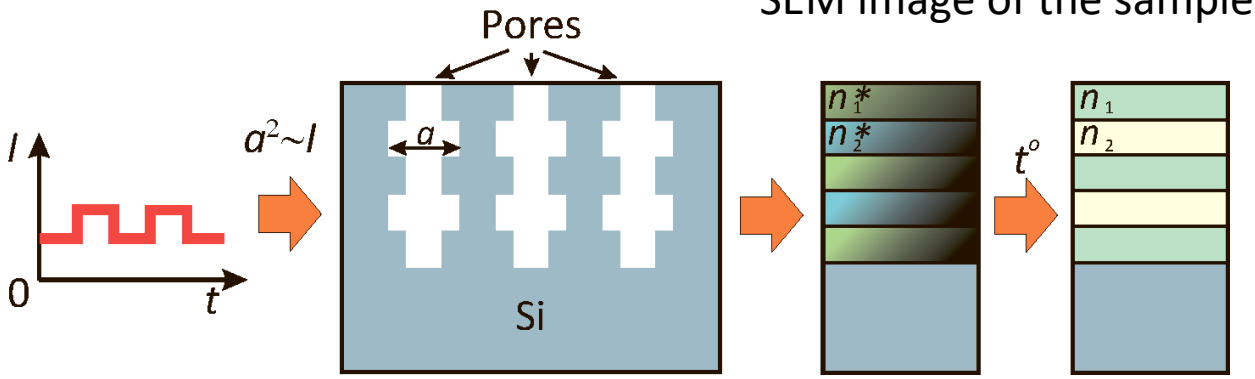
Production of the samples



Electrochemical cell



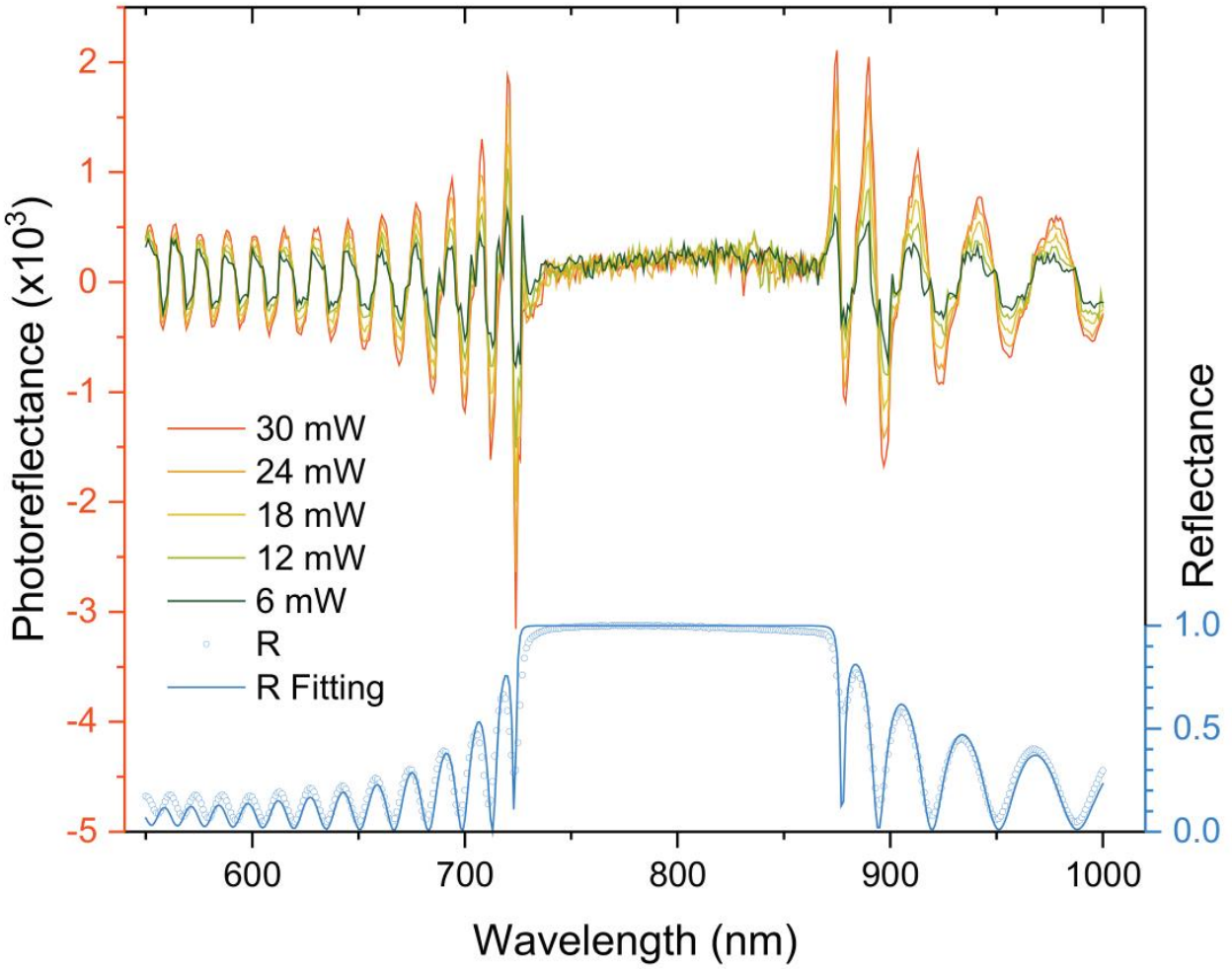
SEM image of the sample (side view)



The etching process of porous silicon photonic structures

S. E. Svyakhovskiy et al. J. Appl. Phys. **112**, 1, 013106 (2012)

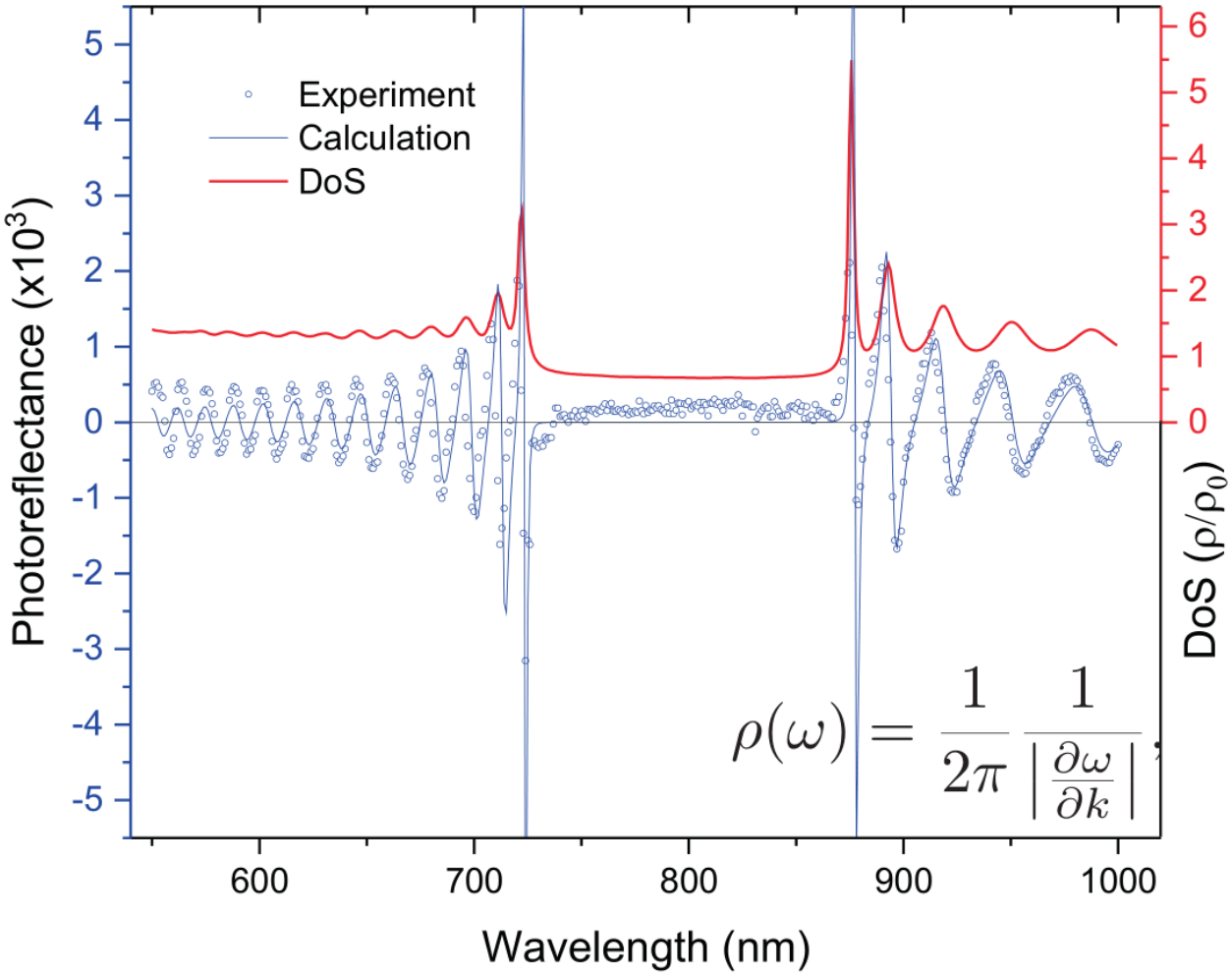
Photoreflectance spectra



The photoreflectance spectra of porous silicon photonic crystal measured at the average pump beam power in range of 6...30 mW compared with the reflectance spectrum.

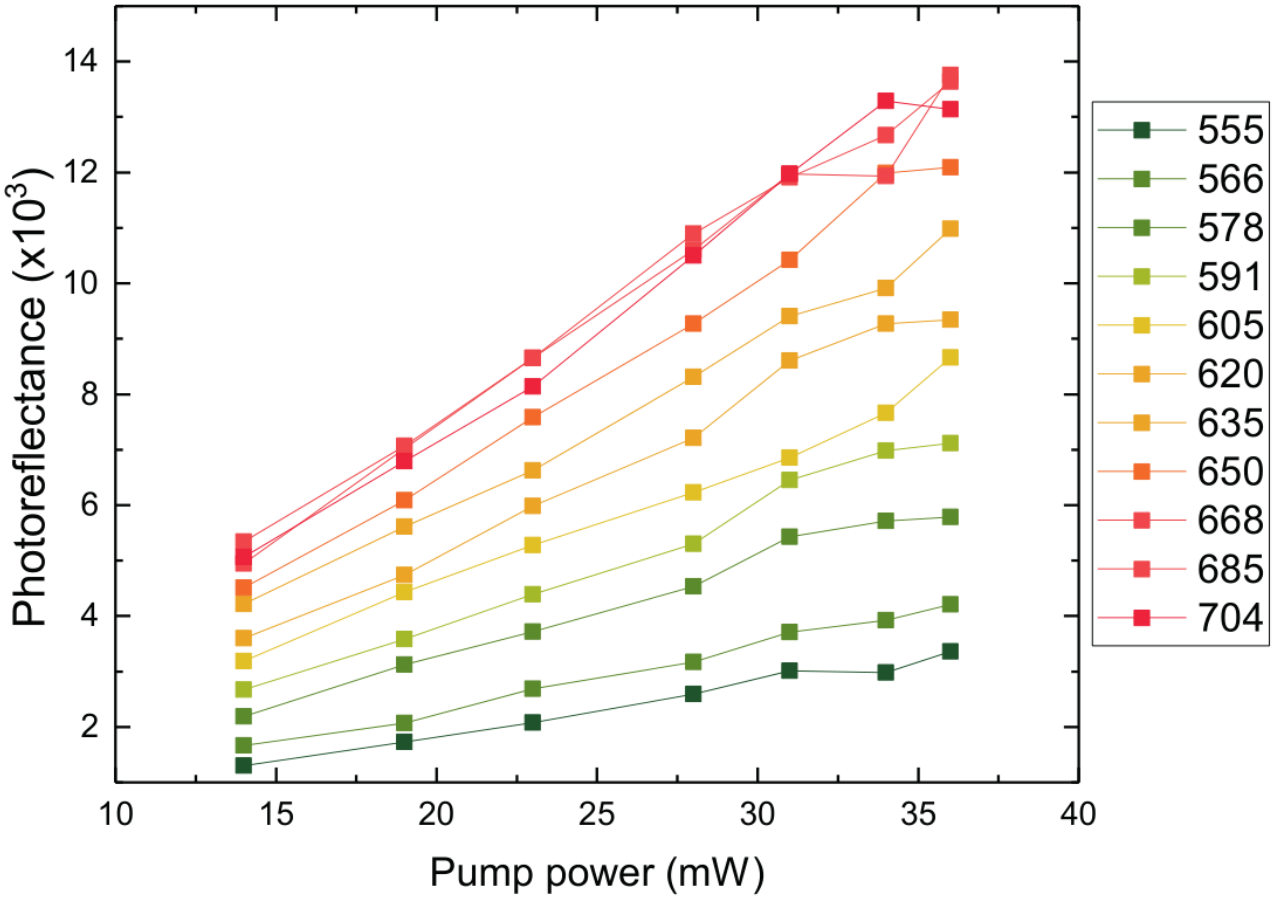
Photoreflectance signal has peaks located at features of the energy spectrum of the photonic crystal.

Density of photonic states



The maxima of PR spectrum coinside with maxima of the density of states (DoS) spectrum. Increasing of the DoS means the decreasing of group velocity causing the light localization and enhancement of the interaction of light and material and leads to the enhancement of photoreflectance.

Spectral dependence



The amplitude of each maximum of the PR signal can be tracked and approximated. The high-precision spectral measurement of the optical nonlinearity was performed.

The mechanism of nonlinearity

The photoreflectance measurement allows to measure the spectral and power dependence of the refractive index variation δn and this is a powerful tool to reveal the mechanism of optical nonlinearity. The linear dependence of δn on the laser power means that the refractive index is linearly dependent on the intensity I:

$$n = n_0 + n_2 I$$

$$n_2 = (4.1 \pm 0.3) \cdot 10^{-6}\ \mathrm{cm}^2/\mathrm{W}.$$

Thermal nonlinearity

We can assume that the nonlinearity observed in our experiments is due to thermal effects that provide a huge nonlinearity. To examine this assumption, we estimated the change of the temperature in single laser shot:

$$\Delta T = \frac{2AI\sqrt{a\tau}}{\sqrt{\pi}k} \approx 0.37 \text{ K}$$

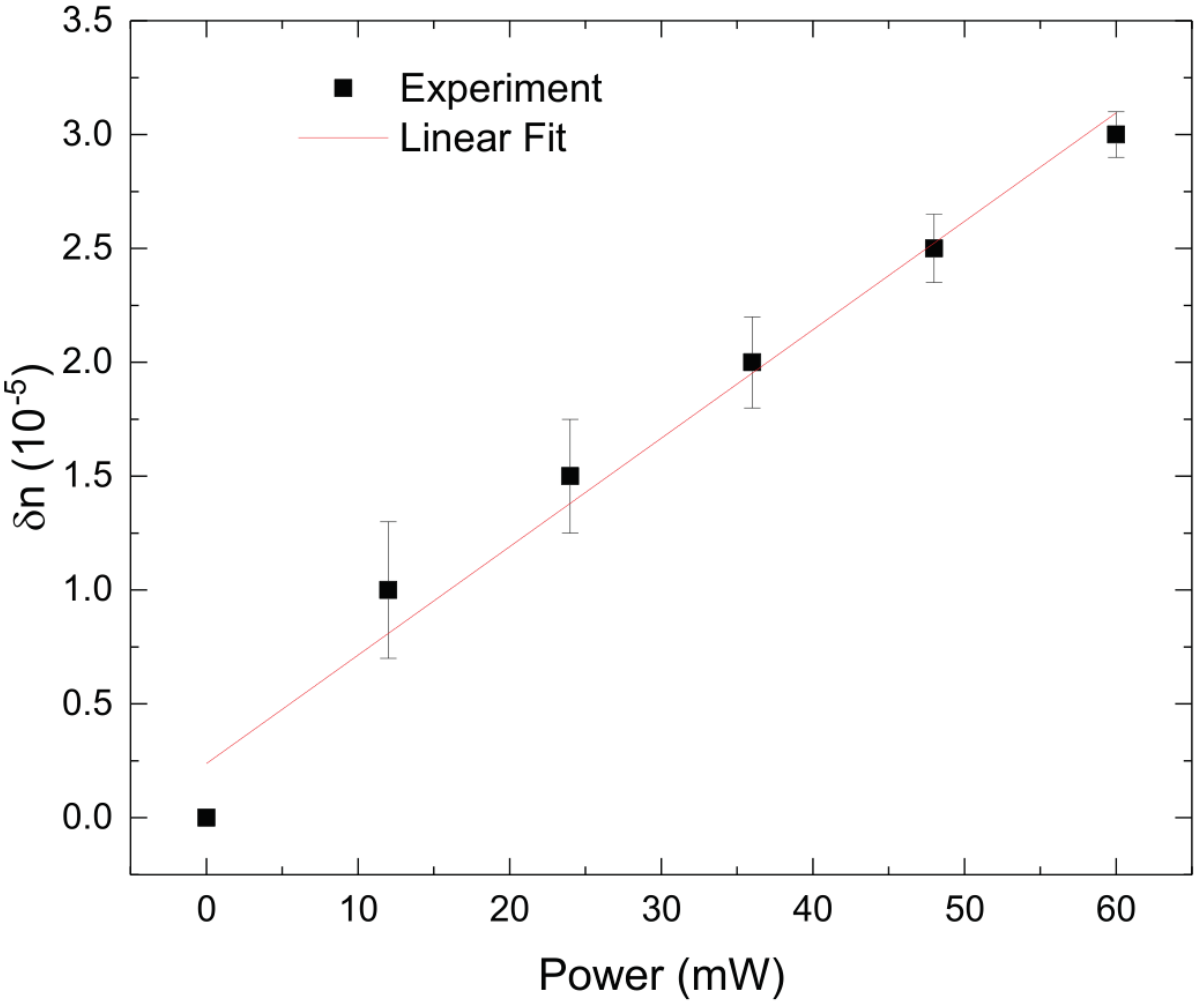
The mesoporous silica is characterized by the thermooptical coefficient

$$dn/dT = 8 \cdot 10^{-5} \text{ K}^{-1}$$

which means the variation of the refractive index of

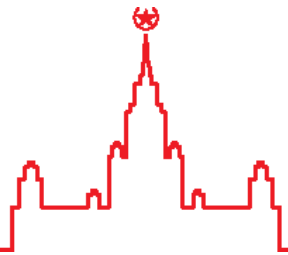
$$\delta n = (dn/dT)\Delta T = 2.98 \cdot 10^{-5}$$

Nonlinear reflectance vs. pump power



The dependence of the refractive index variation on the average pump power.

Conclusions



- We have shown that optical nonlinearity is caused by thermal effects. The thermal coefficient of the refractive index was measured.
- Photoreflectance spectra contain sharp features at energies near the critical points of the band structure of the sample.
- The photoreflectance spectra were fitted with the theoretical model. The variation of the refractive index was retrieved from the model and the lowest pump power (1mW) was as small as 10^-6. These results enable us to measure small variations of the refractive index of porous silicon structures which can be used in biosensing applications.