Influence of electron-phonon interaction on Wannier–Stark effect in macroporous silicon structures with SiO_2 nanocoatings

L. Karachevtseva, Yu. Goltviansky, O. Sapelnikova, O. Lytvynenko and O. Stronska

Photonic Semiconductor Structure Department, V. Lashkaryov Institute of Semiconductor Physics, Natl. Acad. of Sci. of Ukraine. Prospect Nauki, 41, Kiev-03028, Ukraine
E-mail: lakar@isp.kiev.ua

We investigated the contribution of electron-phonon interaction to the broadening parameter Γ of the Wannier–Stark ladders [1] in oxidized macroporous silicon structures with different concentration of Si-O-Si states (TO and LO phonons) revealed in the IR absorption spectra. The growth of the concentration of bridge-like oxygen atoms in Si-O-Si (TO phonons) after addition oxidation of macroporous silicon is due to reduction of the dangling bond passivation in the absence of hydrogen. The LO phonon absorption peaks are formed due to the incident radiation along the surface of cylindrical macropores (geometry of the frustrated total internal reflection as in insertion to Figure).

IR absorption of macroporous silicon samples without oxidation and oxide removal exceeds 4–20 times that of macroporous silicon samples with previous cleaning. The oscillations of IR absorption (Fig., curve 1) result from the electron resonance scattering in a strong electric field by impurity states on the surface of macropores, with the difference between two resonance energies $\Delta E = Fa = 8 \div 20\ \text{cm}^{-1}$ equal to the Wannier–Stark step [1]. The oscillations (Fig., curve 2) have small amplitudes of IR absorption and nearly the same period for samples with surface cleaning as compared with samples of macroporous silicon without previous surface cleaning (Fig., curve 1).

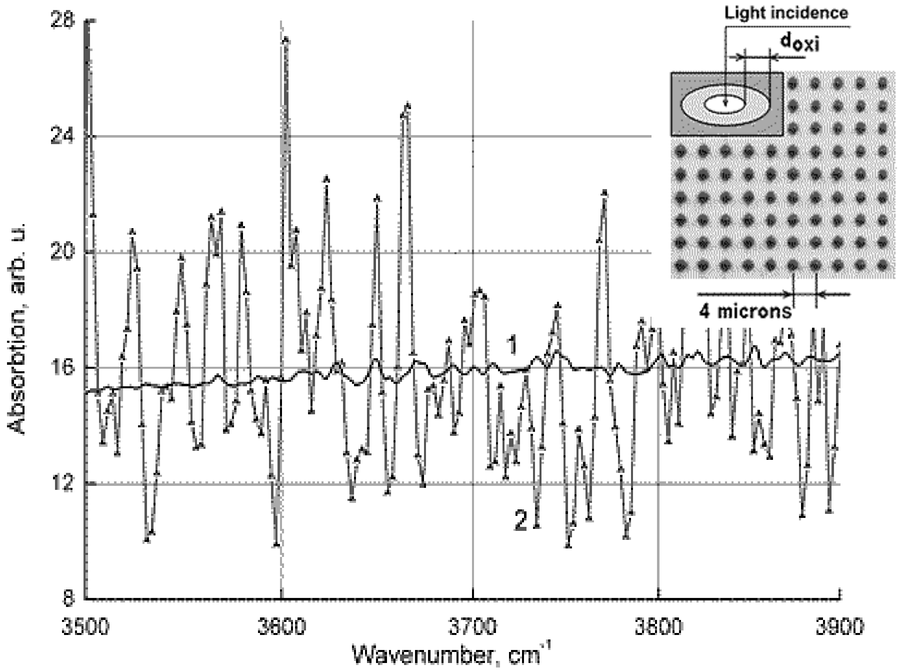

Fig. A fragment of the macroporous silicon structure (insertion) and IR absorption spectra of macroporous silicon having surface oxide 200 nm thick, with (curve 1) and without (curve 2) addition oxidation.

The TO-LO phonon splitting in IR absorption decreases for oxide thickness of 5–50 nm and increases for oxide thickness over 50 nm. The reduction of the TO-LO phonon energy splitting corresponds to the stress relaxation in silicon oxide layer. The increase in the splitting of TO-LO phonons is associated with higher stoichiometry at the silicon–silicon oxide interface as the SiO_2 content in the SiO/SiO_2 mixture increases. A series of light absorption bands at frequencies $\omega \geq \omega_{LO}$ were explained by formation of multi-phonon polariton states [2] as a result of the interaction of phonon polaritons of the SiO_2 film with waveguide modes in the silicon matrix.

We determined the effect of broadening on the oscillation amplitude in IR absorption spectra as convolution of the "nonbroadened" oscillation amplitude with Lorentz distribution. The obtained broadening parameter $\Gamma = 0.3 \div 0.8\ \text{cm}^{-1}$ of the Wannier–Stark ladder is much less than the adjacent level energy evaluated from the giant oscillations of resonance electron scattering on the surface states. The value of broadening parameter Γ is equaled to that for surface phonon polaritons measured in thin films of II–VI semiconductors [2].

Thus, the effect of broadening on the oscillation amplitude in IR absorption spectra is due to interaction of the surface multi-phonon polaritons with scattered electrons. This interaction transforms the resonance electron scattering in the samples without preliminary surface cleaning into an ordinary electron scattering on ionized impurities for the samples with preliminary surface cleaning. The transformation takes place at the scattering lifetime commensurate with the period of electron oscillations in a surface electric field.

1. *Karachevtseva L., Kuchmii S., Lytvynenko O., Sizov F., Stronska O. and Stroyuk A.* Oscillations of light absorption in 2D macroporous silicon structures with surface nanocoatings // Appl.Surf. Sci. – 2010. – **257**, N. 8. – P. 3331–3335.
2. *Vinogradov E.A.* Semiconductor microcavity polaritons // Physics-Uspekhi. – 2002. – **45**, N. 12. – P. 1213-1250.