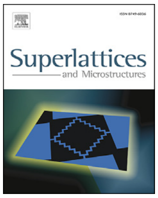
Contents lists available at ScienceDirect

Superlattices and Microstructures

journal homepage: www.elsevier.com/locate/superlattices



Porosity dependence of terahertz emission of porous silicon investigated using reflection geometry terahertz time-domain spectroscopy

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ARTICLE INFO

Article history:
Received 3 May 2016
Received in revised form 27 September 2016
Accepted 19 October 2016
Available online xxx

Keywords:
Porous silicon
Porosity
Absorbance
Terahertz spectroscopy

ABSTRACT

Porosity dependent terahertz emission of porous silicon (PSi) was studied. The PSi samples were fabricated via electrochemical etching of boron-doped (100) silicon in a solution containing 48% hydrofluoric acid, deionized water and absolute ethanol in a 1:3:4 volumetric ratio. The porosity was controlled by varying the supplied anodic current for each sample. The samples were then optically characterized via normal incidence reflectance spectroscopy to obtain values for their respective refractive indices and porosities. Absorbance of each sample was also computed using the data from its respective reflectance spectrum. Terahertz emission of each sample was acquired through terahertz - time domain spectroscopy. A decreasing trend in the THz signal power was observed as the porosity of each PSi was increased. This was caused by the decrease in the absorption strength as the silicon crystallite size in the PSi was minimized.

1. Introduction

Porous silicon (PSi) has been widely used in micro-optics [1], photonics [2], and optoelectronics [3]. Its controllable porosity gives it variable optical, electrical, and optoelectronic properties [4]. Since its discovery, it bridged the gaps that its silicon (Si) predecessors have lacked. To date, studies on PSi have also branched out to the developing field of terahertz (THz) technology. However, most studies are focused on investigation of material properties of PSi in the THz regime [5–7], and emitter application has yet to be developed.

Surfaces of semiconductors are known to emit THz radiation via excitation above the band gap using ultrafast laser pulses. After excitation, the excited photocarriers create picosecond transient currents that, when transformed to frequency domain, is within the THz region of the electromagnetic spectrum [8]. Si is known to generate THz radiation, but only with moderate

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http://dx.doi.org/10.1016/j.spmi.2016.10.052

Please cite this article in press as: A.I. Mabilangan et al., Porosity dependence of terahertz emission of porous silicon investigated using reflection geometry terahertz time-domain spectroscopy, Superlattices and Microstructures (2016), http://dx.doi.org/10.1016/j.spmi.2016.10.052

signal power [9]. However, it has been reported that increasing the surface area of the material through nanostructures can increase its THz emission [10]. On a related note, PSi can be a viable material as a THz source due to its controllable surface area [11,12].

In this work, porosity-dependent THz emission from PSi was investigated. Reflectance spectroscopy was utilized to obtain the refractive indices of each PSi sample. From the computed refractive indices, their respective porosities were also calculated using Bruggeman effective medium approximation. The absorbance of each sample was also computed from its respective reflectance spectra. THz emission was obtained using THz - time domain spectroscopy (THz-TDS). The relationship between the absorbance and corresponding THz emission of the PSi samples was explored.

2. Experimental details

Prior to the fabrication of PSi, 1 cm^2 boron-doped Si (100) samples with resistivity 0.007–0.025 Ω cm were subjected to standard degreasing procedures. The samples were then rinsed with de-ionized water and dried with pressurized high purity nitrogen gas.

The Si samples were then electrochemically etched in a lateral configuration anodization cell. The Si served as the anode, and a silver plate was used as the counter-electrode of the cell. An etching solution composed of 48% hydrofluoric acid, deionized water and absolute ethanol in a 1:3:4 volumetric ratio was used. Anodic current was supplied using a Tektronix PWS4721 programmable DC power supply.

Three pSi samples were fabricated. Etching current densities were varied to obtain different porosities for the PSi [13]. The fabrication parameters are summarized in Table 1. The pore depths of all the samples were designed to be ~2 μm based from calibration experiments. The experimental pore depths were verified via cross-sectional imaging under a Philips XL30 FESEM.

Using normal incidence reflectance spectroscopy, the refractive index of each sample was obtained and subsequently its porosity. A SPEX 500M single grating monochromator was used to disperse the broadband light coming from a tungsten halogen lamp. The light was then focused to the PSi sample and the reflected light was directed to a Si photodiode. Standard lock-in techniques were used to obtain data. The setup is shown in Fig. 1.

To measure the THz emission of the samples, a standard reflection geometry THz-TDS system was used. The excitation source was a Ti:sapphire femtosecond pulsed laser centered at 800 nm, with pulse width of 100 fs and repetition rate of 80 MHz. The excitation beam was split into a pump arm and a probe arm. The pump arm was incident onto the PSi sample for THz generation. The emitted THz radiation of the PSi was collected and collimated by *f*-matched paraboloid mirrors. The emission was focused and directed into a LT-GaAs photoconductive antenna (PCA) for detection. The PCA detector is triggered optically by the probe arm. The emission was temporally resolved by a time delay introduced in the pump arm. The schematic of the setup is shown in Fig. 2.

Table 1
The etching parameters used in fabricating the PSi samples.

Sample	Anodic current density (mA/cm^2)	Etch time (sec)
PSi A	2.5	1000
PSi B	5.0	625
PSi C	15.0	278

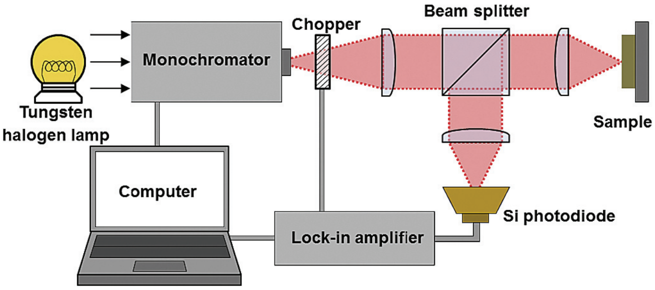

Fig. 1. Schematic diagram of the normal incidence reflectance spectroscopy setup used to acquire the refractive indices and porosities of the PSi samples.

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