3-level broadband THz antireflective structure on silicon surface

I.A. Tzibizov[1], G.I. Kropotov[1], V.S. Pavelyev[2,3], K.N. Tukmakov[2,3], A.S. Reshetnikov[2,3]

[1]Tydex LLC, 16, Domostroitelnaya st., 194292, St. Petersburg, Russia
[2]Samara University, 34, Moskovskoe shosse, 443086, Samara, Russia
[3]IPSI RAS - Branch of the FSRC “Crystallography and Photonics” RAS, Molodogvardeyskaya 151, 443001, Samara, Russia

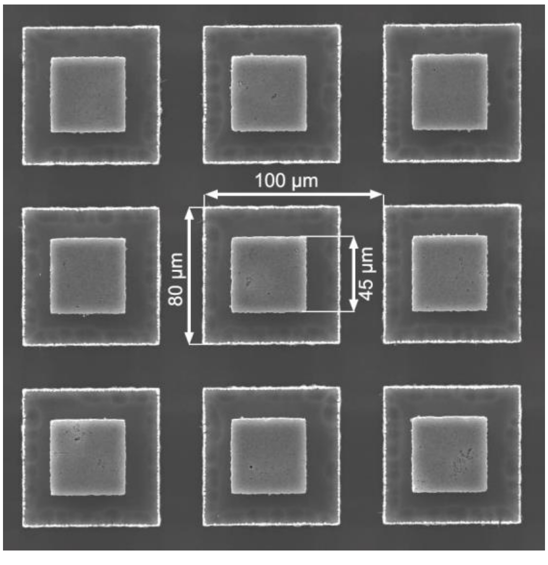
The development and production of broadband antireflection coatings for the THz frequency range has been a promising and relevant task for several years. Currently, only antireflection coatings optimized for a specific frequency and representing a polymer film deposited on an optical element are commercially available [1].

In this paper we want to show the results of research on the antireflection properties of a three-level structure fabricated on a low-resistance silicon substrate. Here, broadband antireflection (BBAR) structure was required to manufacture a broadband THz radiation absorber. Such a broadband perfect absorber can be used as a sensitive element in THz imaging systems [2] or THz waves detection [3]. Antireflection properties of BBAR structure were obtained using THz time-domain spectroscopy (THz-TDS) methods.

As a substrate for a THz absorber, we decided to use a low-resistivity silicon, since it has a high absorption in the THz range. It was necessary to reduce Fresnel losses on air-substrate interface to increase the amount of absorption. For this, we decided to create an antireflective coating [4] or antireflective structure [5] on one side of the silicon substrate.

To realize a broadband antireflection effect, we produced a 3-level structure on the one side of the silicon substrate. Such a structure was realized by the method of reactive ion etching (Bosch process) [4,6].

To produce a sample device we used p-type silicon substrate with a diameter of 50 mm and 500 μm thickness (Fig. 1).



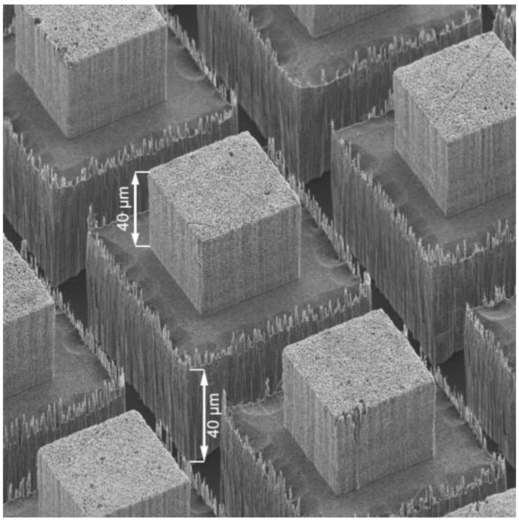


Fig. 1. Scanning electron microscope (SEM) images of the sample device

To characterize the antireflective properties of the produced sample, the transmission and reflection measurements were carried out on the free-space PCA-based terahertz time-domain spectroscopy (THz-TDS) system.

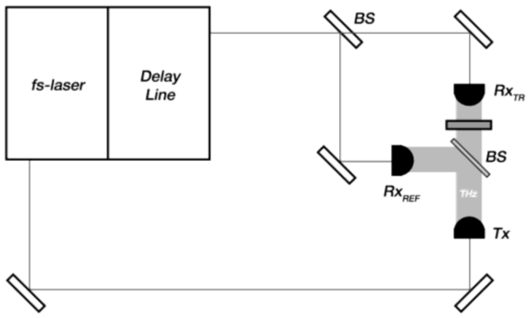


Fig. 2. Experimental setup

THz-TDS system operates in 0.2-2.5 THz range and has a spectral resolution of at least 5 GHz. General scheme of a system and the experimental setup is shown on Fig. 2. In our experiments we measured both, bare silicon substrate and fabricated sample with 3-level antireflective structure. Reflectance was measured under the normal angle of incidence. Reflection from the one side of a sample decreased from 28-30% to less than 3% in 0.5 – 2 THz range (Fig. 3). The absorption spectra of the sample is presented in Fig. 4.

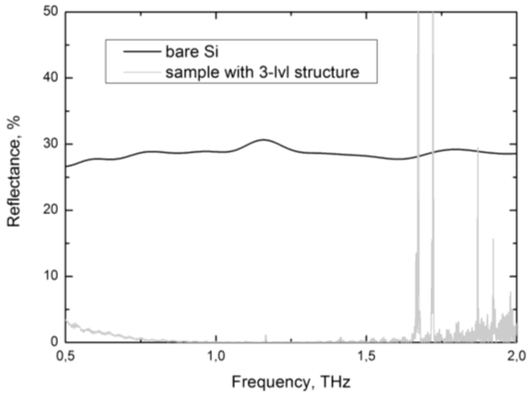


Fig. 3. Reflectance spectra of the produced sample

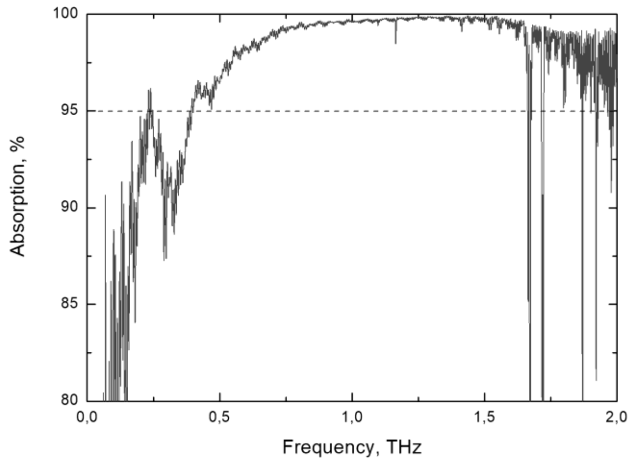


Fig. 4. Absorption spectra of the produced sample

In conclusion, it meant to be said that such structures can be used for reflection reduction at the air-silicon interface of transmissive silicon optical elements [4,6] in the broad range of the THz frequencies. Also, it could be optimized for the certain frequency range.

Acknowledgements

The spectral measurements partly were supported by RFBR grant (№ 18-29-03303).

References

1. *A. J. Gatesman, J. Waldman, M. Ji, C. Musante, and S. Yngvesson*, An Anti-Reflection Coating for Silicon Optics at Terahertz Frequencies // IEEE Microwave and Guided Wave Letters, 10, 7, pp 264 – 266 (2010).
2. *C.Shi et al.* Ultra-broadband Terahertz Perfect Absorber Based on Multi-frequency Destructive Interference and Grating Diffraction // (2014)
3. *J. Lehman, A. Sanders, L. Hanssen, B. Wilthan, J. Zeng, C. Jensen*, Very black infrared detector from vertically aligned carbon nanotubes and electric-field poling of lithium tantalite // Nano Letters, 10, 3, P. 3261 (2010).
4. *A.N. Agafonov, B.O. Volodkin, A.K. Kaveev, B.A. Knyazev, G.I. Kropotov, V.S. Pavel'ev, V.A. Soifer, K.N. Tukmakov, E.V.Tsygankova, Yu.Yu. Choporova*, Silicon diffractive optical elements for high-power monochromatic terahertz radiation, Optoelectronics, Instrumentation and Data Processing, 49, pp. 189-195 (2013)
5. *C. Brückner, T. Käsebier, B. Pradarutti, S. Riehemann et al*., Broadband antireflective structures applied to high resistive float zone silicon in the THz spectral range, Optics Express, 17, 5, P. 3064 (2009).
6. *A.N. Agafonov, B.O. Volodkin, D.G. Kachalov, B.A. Knyazev, G.I. Kropotov, K.N. Tukmakov, V.S. Pavelyev, D.I. Tsypishka, Yu.Yu. Choporova, A.K. Kaveev*, Focusing of Novosibirsk Free Electron Laser (NovoFEL) radiation into paraxial segment, Journal of Modern Optics, 63, 11,pp. 1051-1054 (2016)