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Polyethylene-on-quartz platform for subterahertz reconfigurable reflective surfaces

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Abstract. Subterahertz frequency band is preallocated for the deployment of sixth generation wireless networks. Mastering of this band is challenging and requires development of appropriate hardware and software. The properties of components used should be authentically known for the purpose of accurate designing and prototyping. This research focuses on the radio-physical properties of a polyethylene-on-quartz sandwich as a potential dielectric platform for the implementation of reconfigurable reflective surfaces. The sandwich is exposed to spectral studies, statistical analysis of feasible fabrication tolerances and compatibility with cleanroom metal deposition and patterning processes. Its technological robustness is assessed upon prototyping of a 16-element planar reflectarray designed for operation in specular and non- specular reflection regimes at 155 GHz and 120 GHz, respectively. Using the measured value of quartz permittivity of a 3.55 and the loss tangent of a 0.001, we calculate the reflectarray reflection losses of approximately 1.5 dB. The calculations agree well with the results of its radiation pattern measurements conducted at 155 GHz. This hints that the developed passive platform is suitable for integration with A3B5 active layers with nonlinear elements ensuring fast beam steering in the subterahertz band.

Keywords: subterahertz, polyethylene-on-quartz, permittivity, reconfigurable reflective surface, reflection loss, 6G network

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Платформа полиэтилен-на-кварце для субтерагерцовых реконфигурируемых отражающих поверхностей

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Аннотация. Это исследование сосредоточено на радиофизических свойствах бислоевой структуры полиэтилен-на-кварце как потенциальной диэлектрической платформы для реализации реконфигурируемых отражающих поверхностей. Структура подвергается спектральным исследованиям, статистическому анализу возможных технологических допусков и совместимости с процессами осаждения металла и формирования рисунка в чистой комнате. Расчеты хорошо согласуются с результатами измерений диаграммы направленности, проведенных на частоте 155 ГГц. Это указывает на то, что разработанная пассивная платформа пригодна для интеграции с активными слоями A3B5 с нелинейными элементами, обеспечивающими быстрое управление пучком в субтерагерцовом диапазоне.

Ключевые слова: субтерагерцовый диапазон, полиэтилен-на-кварце, диэлектрическая проницаемость, реконфигурируемая отражающая поверхность, потери на отражение, сеть 6G

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Introduction

Subterahertz (sub-THz) frequency band is pre-assigned for the deployment of wireless networks of the sixth generation (6G). Mastering of corresponding carrier frequencies is laborious due to some specifics. Therefore, there appears a necessity to develop appropriate hardware and software. The properties of components that are used should be reliably known. So that it leads to the increasing accuracy of design and implementation of 6G wireless modules and systems. This research is focused on the radiophysical properties of a metallization-equipped polyethylene-on-quartz platform potentially suitable for the implementation of reconfigurable reflective surfaces. A series of measurements of the reflection spectra of a 140 μm thick quartz substrate in both *s*- and *p*-polarizations is carried out at 130–160 GHz. The quartz substrate is exposed to V/Cu (5/200 nm) and Ti/Au (10/300 nm) deposition and patterning on the front and rear sides. Its front side is further coated by a 100 μm thick polyethylene layer, whose surface is exposed to V/Cu (5/400 nm) deposition and patterning at the later stage. The resulting structure has a nominal geometry identical to that reported by us earlier in [1], yet the actual linear and angular dimensions differ from their nominals due to fabrication errors. The unit cell model of the reflectarray [2] is accordingly adjusted, and its simulated performance is further experimentally justified.

Materials and Methods

In our spectral studies intended to distinguish exact relative permittivity of the chosen quartz substrate potentially ranging from 3.5 to 4.5 [3], the quartz material under the test (MUT) is represented by a two-inch diameter wafer. The thickness of the MUT is 140 μm. In order to evaluate the permittivity of the MUT, we assess the reflective properties of the material. The experimental setup along with the employed methods are described by us in details elsewhere [4]. The optical paths between 130–160 GHz transmitter (Tx) and receiver (Rx) with respect to MUT are identical and equal to Fraunhofer distance (FD).

Once the dielectric and conducting properties as well as the actual geometry of the developed V/Cu / polyethylene / V/Cu / quartz / Ti/Au reflectarray structure are assessed, we measure its radiation pattern in the far-field and evaluate reflection losses at 155 GHz. The same set up is used as well. In order to analyze the losses the radiation pattern of the array-sized mirror is also measured in the similar manner.

Results and Discussion

We conduct measurements for the angles of incidence θ equal to 30, 45, 60 deg and consistently acquire MUT's complex permittivity of 3.55 (1 + 0.001*i)* for both transverse electric (TE) and transverse magnetic (TM) waves. Note that the angle θ equal to 60 deg is close to the Brewster's angle. Using the characteristic matrix (CM) [5] based fitting of the experimental spectral data, we achieve measurement accuracy of approximately 10–20%. The CM fit-functions are compared with the predictions of Fresnel equations (FE). CM was implemented due to the thickness of the sample as FE are not applicable for thin-layered media. Our findings are summarized in (Fig. 1, *a*, *b*) and (Fig. 2, *a*).

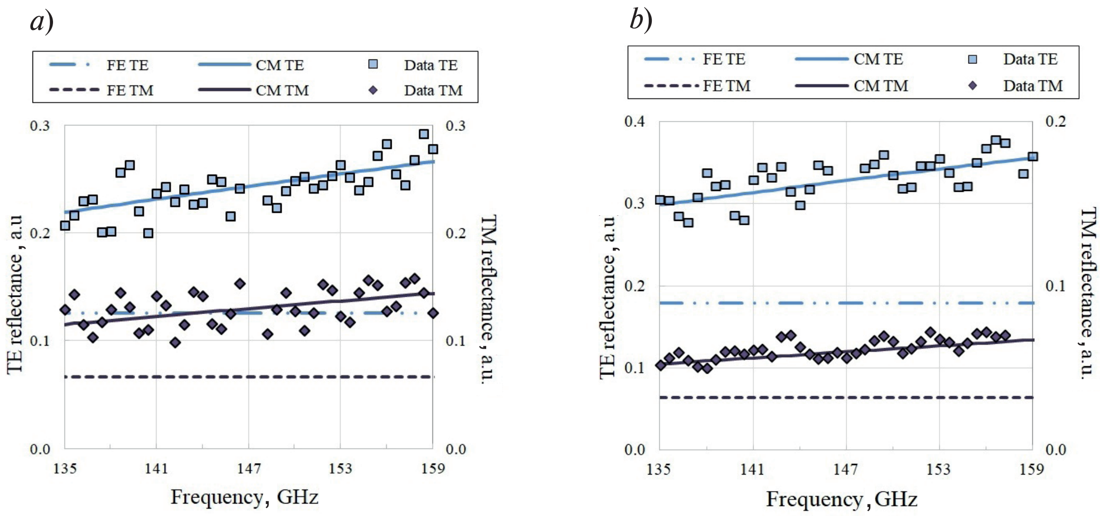

Fig. 1. Reflection spectra of the quartz substrate at θ = 30 deg (*a*); reflection spectra of the quartz substrate at θ = 45 deg (*b*)

As far as properties of the substrate of reflectarray are assessed we measure the far-field radiation pattern of the structure at a carrier frequency 155 GHz. We are interested in this frequency as the electromagnetic (EM) modeling predicts the reflection losses of approximately 1.5 dB and the mirror-like behavior of the reflectarray structure with adjusted parameters of quartz wafer. To confirm the accuracy of EM modeling and to evaluate the reflection losses we also analyze the pattern of the array-sized mirror measured in the same setup. Signal intensity drops obtained in the radiation pattern are due to the geometry of the device with corresponding additional losses introduced by layers into the structure.

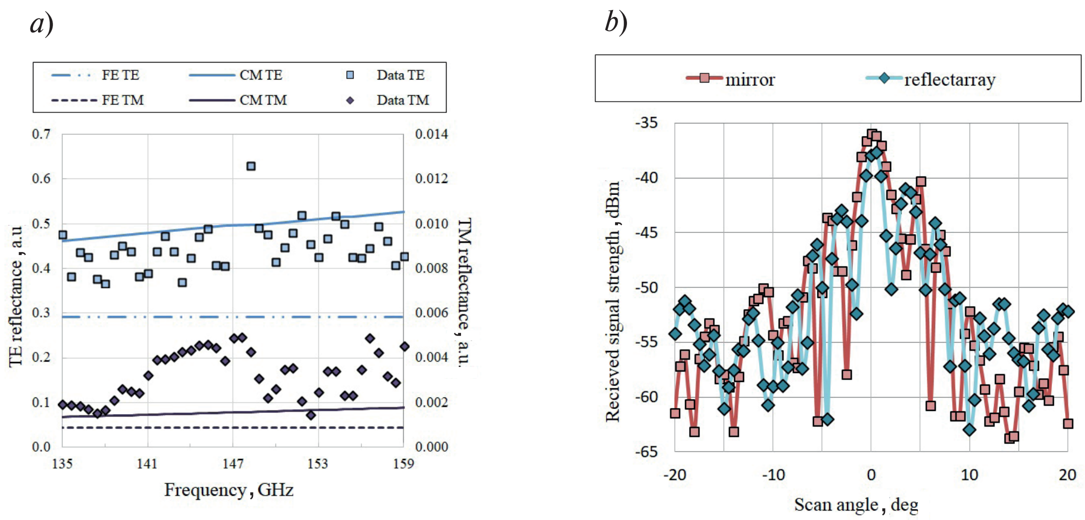

Fig. 2. Reflection spectra of the quartz substrate at θ = 60 deg (*a*); far-field radiation patterns of the fabricated reflectarray and the array-sized mirror measured at 155 GHz (*b*)

Experiments reveal excessive losses of 1.5–2 dB as compared to those of mirror. Our findings are summarized in (Fig. 2, *b*).

Both experiments and simulations consistently validate relevance of the reflectarray design in terms of radiophysics and hint its technological robustness in terms of fabrication tolerances and compatibility with cleanroom processes.

Conclusion

In this paper, we report on the reflective and refractive properties of quartz wafer as a substrate for reflectarray and the reflection losses of the fabricated reflectarray. An appropriate measurement setup is developed. The experimental value of dielectric permittivity of quartz is $3.55 + 0.0035i$. The measured reflectarray losses of approximately 1.5–2 dBm at 155 GHz are consistent with one calculated. Overall, we can conclude that the developed passive platform is suitable for integration with A3B5 active layers with nonlinear elements ensuring fast beam steering in the sub-THz band. This should be interesting to developers of reconfigurable reflective surfaces for reflection-aided 6G wireless channels.

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