Laser micromaching for metamaterials manufacture

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Abstract

This paper presents an alternative method of metamaterials manufacture for radio frequency (S-band). We propose laser micromaching for directional changing properties of aluminium nitride (AlN) surface in order to obtain a conductive trace. This method was verified and compared with the traditional method – photolithography.

1. Introduction

Over the last decade the field of science related to metamaterials has significantly developed. More and more research teams focus on this subject area due to unconventional properties of the medium created of the metamaterial. Phenomena occurring in a metamaterial have a well-developed theoretical background [1-2]. Presently the greatest problems, that the research teams face, are the technological limitations. In a traditional technology of metamaterial structures implementation there are used printed circuit boards (PCB), which metallized surfaces obtain desired geometry in the photolithography process. This process is complex and requires adequate material preparation which makes the process time-consuming. Our proposal is to use AIN ceramics which surface will be modified in laser micromachining process [3]. Proposed by us material, apart from low thermal resistance, undergoes surface metallization as a result of laser beam impact. This allows to manufacture periodic metallic structures. The laser micromachining process enables fast prototyping directly on a material surface. This allows to significantly reduce time related to physical model production of metamaterials.

2. Producing conductive structures on AIN ceramics surface

The key aspect of the proposed method of producing metamaterials is a possibility of direct AIN ceramics metallization in the micromachining process, by reducing aluminium nitride to the metallic form. With the use of pulse fiber laser with the maximum output power at the level 20W and the pulse duration of 100ns, the supplied energy contributes to the rupture of aluminium and nitrogen bonds. Nitrogen evaporates to the atmosphere, and aluminium molecules are sintered due to the heat [4]. This method allows to eliminate photolithography processes, to obtain higher resolution (miniaturization) and significant time reduction when prototyping new structures. Conducted by us research so far has displayed a possibility to produce low-ohm contacts ($<3\Omega$) on AIN surface. Figure 1 presents the measurements results of tracks resistance 1 mm wide in the 15 mm segment (Fig.1b). The paths have been manufactured in three different gas environments (air, nitrogen, argon). As it can be observed, the paths manufactured with the presence of argon display the lowest resistance at the level of 0.057Ω.

The measurements were obtained with the use of the four-edged probe. Obtaining narrow low-ohm paths allowed us to manufacture a single metamaterial structure in form of the resonator spirals or inductors.

a) b)

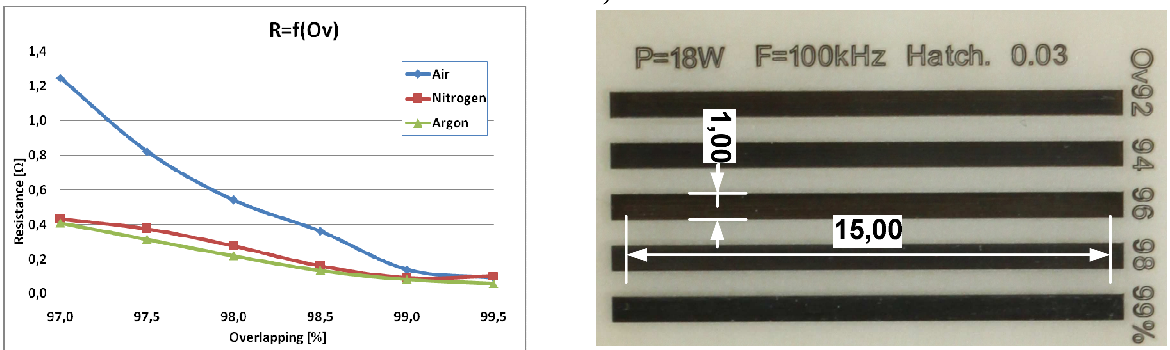

Fig.1 Results of the metallic layer resistance a) resistance (L = 15mm s = $6\cdot10^{-3}$ mm^2) as a function of the pulses overlapping O_v (for parameters: λ = 1064nm, P = 18W, hatching h = 0,02mm, laser repetition frequency F_r=20kHz, and three process gases: air, nitrogen and argon, b) manufactured structures enlargement (L = 15mm, w = 1mm)

If the TEM wave falls perpendicularly at the resonant circuit, a structure displays running properties in the forbidden band (incident wave attenuation). The operating band results from the geometry of the metallic paths (capacitance, inductance) [5] which have been approximately estimated on the basis of the conducted simulations with the use of FDTD method (CST Microwave Studio). As a result of the simulation, the accepted size of a single cell is 6x6x0.5mm, and the width of the metallized paths equals 0.3mm, while the distance between the paths is 0.3mm. The entire metallization length is 22.8mm for AlN (ε_r=8.6, tan=0.0003, thickness 0.5mm).
Figure 2a displays the simulation outcome for the above mentioned structure. The designed structure has greater than 10 dB attenuation for 250MHz band. Figure 2b presents the enlargement of the single cell manufactured by laser micromachining in a direct ceramics metallization. It may be also observed that, on account of the laser metallization, the path consists of several sub-paths related to the course of laser radiation.

a) b)

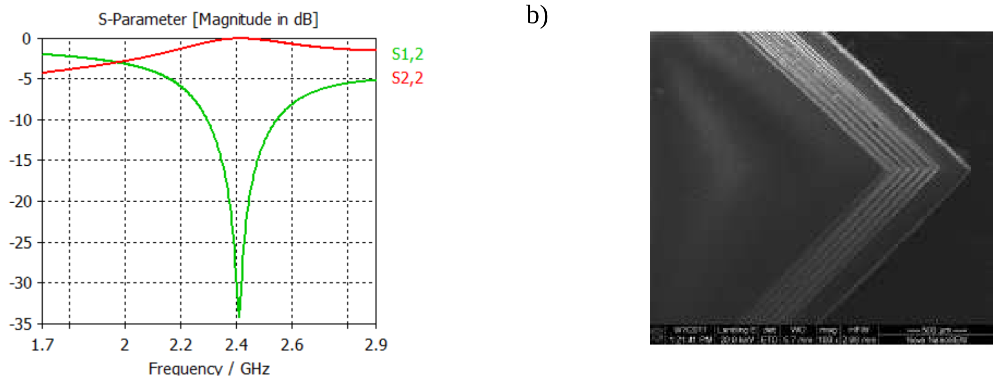

Fig.2 SR-AlN structure a) Simulation outcome b) zoomed sample structure view

3. Results

The measurements were made in the scope of two microstrip patches antenna away from one another by 65 mm (λ/2). For this purpose the antenna was designed on a polypropylene substrate of a constant dialectic permeability (ε_r=2.2, tan=0.0003, thickness 6mm). SR were positioned transversely in a dialectic antenna substrate. The cells were placed in a row with 3mm periode. The measurements were taken in the anechoic chamber with the use of ZVA50 (Rohde&Schwarz) network analyzer - Fig.3a. In order to compare the proposed method with the traditional photolithography method, two sets of structures were manufactured using the above mentioned methods. The former one comprises the usage of direct AlN ceramics surface metallization with the use of laser radiation of 1064nm wave scope of total metallization length of SR 22.8mm and the second set was made by the traditional photolithography method on RO4003 laminate (ε_r =3.38, tan=0.0021, thickness 20 mils / 0.508 mm) for the SR length of 29.6 (Fig.3a). Metallization length is related to dielectric permittivity of the materials used as the substrate. The results of the conducted measurements are presented in fig.3b. The structure manufactured on AlN ceramics has a broader band (100MHz) forbidden with reference to the cells made on RO4003 laminate. The maximum suppression value in peak is comparable for both sets of SR structures manufactured by two methods.

a) b)

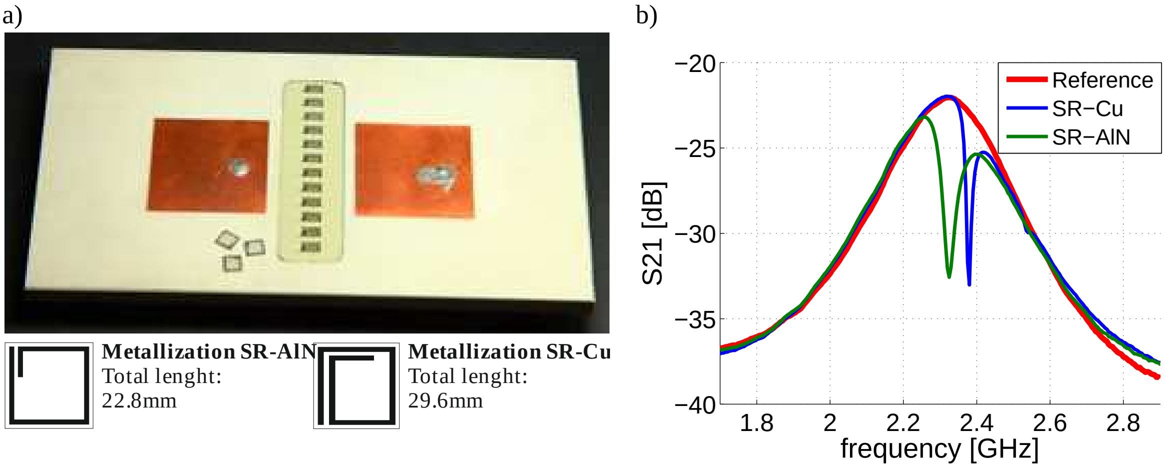

Fig. 3. Measurements of SR structure a) The illustration of integrated measurement module together with the manner of placing the investigated structures and the shape of the manufactured re sonant circuits b) The comparison of the obtained results for SR-Cu and SR-AlN structures

4. Conclusions

The proposed by us method of metamaterial structures manufacture provides many advantages. Firstly, it allows for the rapid projection of the designed structures directly on the metamaterial surface (the AlN ceramics in this case), without either the redundant preparation of masks or material surface as in case of a traditional photolithographic method. A subsequent virtue is obtaining a broader band forbidden for metamaterials manufactured on the RO4003 laminate by the photolithography. The additional trumps of the proposed process are: high precision in the surface structuring and a possibility to manufacture many metamaterial structures in a single technological process. Due to high precision (the order of micrometers) resulting from a diameter of the laser beam the proposed micromachining process is suitable for manufacture such types of structures in a microwave band.

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