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Cu Based Patch Antenna on Polymer Substrate for Flexible Wireless Sensor Systems Applications

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Abstract

In this work we designed, simulated and developed a flexible 10 GHz patch antenna using standard microsystem technology. Liquid crystal polymer (LCP) is used as substrate and Copper (Cu) as metallization thin film. LCP and Cu are best suited for high frequency applications because of their excellent electrical properties such as resistivity and dielectric constant. To protect the antenna it is passivated and encapsulated with parylene C. Parylene C was deposited at room temperature using standard Gorham system. The effect of Cu metallization and parylene C passivation on antenna indicator parameters such as resonance frequency, input reflection coefficient, bandwidth and gain are investigated. Furthermore the specific resistance of Cu lines on LCP substrates is investigated.

Keywords: Flexible Sensor, LCP, Patch antenna, Wireless Sensors.

1. Introduction

Nowadays there is a continuous expansion of wireless sensor system applications for example in aircraft monitoring systems, collision warnings in cars or remote patient monitoring systems. The suitable system for these applications must be robust and also flexible. Furthermore these applications require higher transmission speeds, and therefore higher bandwidth, which shifted the working frequencies of the transmission systems to higher frequency bands. Aluminum, as standard thin film metallization for these applications, faces its physical limit. Therefore it is important to find an alternative metallization.

Cu with smallest electrical resistivity after silver is a promising substitute for the aluminum [1]. One of the essential parts of any wireless sensors is Antenna. In this work we investigate the properties of a Cu based micro patch antenna on flexible polymer substrate (LCP) and with parylene C passivation.

The liquid crystal polymer LCP is a flexible organic material with attractive properties for high-frequency and packaging applications. Its excellent electrical properties such as low dielectric permittivity = 2.9, low loss factor (tan δ = 0.002) and stability over a wide frequency and temperature range made it a suitable material for high

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frequency applications [2], [3]. Furthermore liquid crystal polymers has good mechanical properties, low thermal expansion and very low moisture absorption (0.04%) and is chemically resistant [4].

For above mentioned applications it is necessary to protect the antenna against moisture, heat and other environmental influences. For this task parylene C was used as the insulator layer. Parylene C is a transparent polymer with better mechanical properties and biocompatibility than normally used SiO_2 and Si_3N_4. It has a dielectric constant of about 3.1 at 1 kHz, which is also comparable to that of SiO_2 and Si_3N_4. Parylene C is deposited using a modified Gorham process. In this four-stage process, the parylene dimmer first vaporizes at 150°C, the reactive monomers are then produced at a temperature of 650°C and pumped into the polymerization chamber. At the third stage, the active monomers of parylene are polymerized on the surface of the object at room temperature. In the end stage the residue of the process are cooled down to –70°C and removed [5].

2. Experimental details

Fig. 1 shows the schematic representation of a 10 GHz antenna. The antenna was realized on a LCP substrate with a thickness of 100 µm and ε_r of 2.9. The thickness of the copper metallization was varied from one to five times of penetration depth (the depth at which the intensity of the radiation inside the material falls to 1/e of the original value at its surface). The antenna dimensions were calculated analytically and optimized with a simulation program (Table 1).

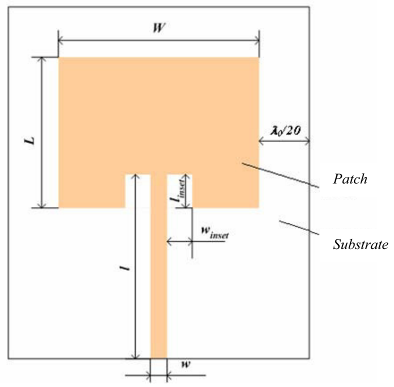

Fig. 1: Schematic representation of the realized antenna structure

Table 1: Geometry details of the realized antenna structure

L [mm]	W [mm]	w [µm]	l [mm]	winset [µm]	linset [mm]
8,72	11	260	9,8	260	2

3. Results and discussion

3.1. Effect of Metallization Thickness

The S parameters of the antenna are measured using network analyzers (Agilent 8719D). The antenna indicator parameters such as resonance frequency, input reflection coefficient, bandwidth and gain are calculated using these parameters (Table 2). The minimum of the S_{11} parameter is considered as the resonance frequency and the efficiency of the antenna is determined with the help of the Wheeler-cap method where:

$$\eta = \frac{Z_w\left(\frac{1+S_{11}}{1-S_{11}}\right) - Z_w\left(\frac{1+S_{11}{}^{wc}}{1-S_{11}{}^{wc}}\right)}{Z_w\left(\frac{1+S_{11}}{1-S_{11}}\right)} \Rightarrow \eta = 1 - \frac{(1-S_{11})(1+S_{11}{}^{wc})}{(1+S_{11})(1-S_{11}{}^{wc})}$$

Investigations show that with increasing Cu thickness, the resonance frequency of the antenna is shifted to lower frequency value. The input reflection coefficient decreases with increasing of the Cu thickness (Fig. 2). But no reductions of the S_{11} parameter could measure after a layer thickness more than twice the skin depth. The efficiency of the antenna increases with increasing metallization thickness.

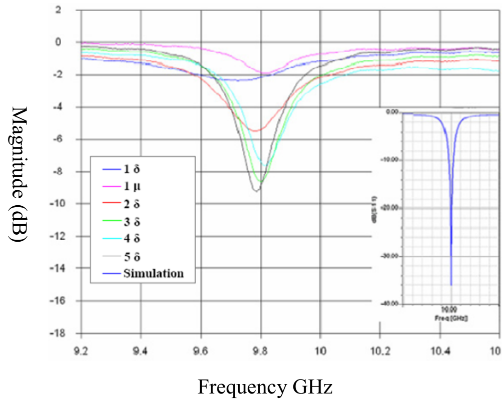

Fig. 2: Measured and simulated input reflection coefficients for the 10 GHz antenna on LCP with different Cu thickness

Table 2: Characteristics of the 10 GHz antenna on LCP with different metallization thickness

Cu-Thickness [µm]	Fr [GHz]	S11 [dB]	η [%]
0.66	9.7	-2.4	7.5
1	9.815	-1.9	19
1.32	9.78	-5.42	12.5
1.98	9.8	-8.6	16.56
2.64	9.82	-7.62	12.1
3.3	9.78	-9.23	24.3

3.2. Effect of Parylene C Encapsulation

To protect the antenna from the harmful environmental effect the entire antenna surface is encapsulated with an additional parylene C layer. Afterwards the effects of passivation layer on the antenna indicator parameters are measured. Because of the very thin parylene C layer (4 times bigger than skin depth) only a small resonance frequency shifts to the lower values and no change in bandwidth of antenna is observed (Table 2).

Table 2 Characteristics of the 10 GHz antenna on LCP after parylene C encapsulation

Δfr/fr [%]	Fr [GHz]	S11 [dB]	η [%]
0.6	9.74	-10.78	17.8

3.3. Resistivity of Cu on LCP

Specific resistance is an important parameter for the stability and electrical migration characteristic of Cu thin film. The specific resistance of Cu is measured using "van der Pauw" method and a "Greek Cross" structure with a width of 200 and a length of 650µm. A relative high specific resistance of about $7.1 \cdot 10^{-6}$ Ωcm is measured. This might be happen, because of the porosity of the LCP surface after the etching process (Fig. 3 a & b). The porosity of the LCP surface can also lead to relatively low activation energy and less electro migration stability of the Cu layer on LCP substrate.

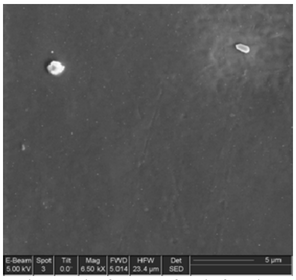

Fig. 3: a- REM micrograph of LCP surface before the etching process.

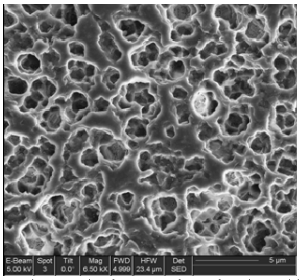

Fig. 3: b- REM micrograph of LCP surface after the etching process

4. Conclusions

In this work we designed, developed and test a flexible patch antenna using Cu as metallization and LCP as substrate. To protect the antenna against harsh environment the whole system is capsulated with parylene C. Investigations show that with increasing Cu thickness, the resonance frequency decrease. The input reflection coefficient also decreases with increasing of the Cu thickness but no reductions could measure after a layer thickness more than twice the skin depth. The efficiency of the antenna improved after increasing metallization thickness. After covering the entire antenna surface with the additional parylene C layer, the resonance frequency decrease. A relative high resistivity of Cu thin film is observed which can lead to less stability of Cu layer on LCP.

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