Experimental Characterization of Silver Nanofilm Proximity Coupled Microstrip Patch Antenna

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Abstract— **In this paper we report experimental characterization of microstrip patch antenna using physical vapour deposited silver nanofilm of thickness 30 nm (less than 57 nm, electron mean free path of silver). The silver radiating nanofilm is fed by electromagnetically coupled mechanism also known as proximity coupled feeding scheme where there is no physical contact between silver nanofilm and bulk copper feeding arrangement. The experimental result shows excellent response in terms of bandwidth. These antennas are attractive for a wide range of applications from wireless weather monitoring to satellite communications.**

Keywords— **Nanofilm, proximity coupled patch antenna.**

I. INTRODUCTION

There is a lot of research on microstrip patch antennas for size reduction and bandwidth improvement, since these classes of antenna have narrow bandwidth, lower power handling capacity and gain [1]. Over years, antenna size reduction have been achieved by radiating patch modification like introduction of slits, slots, parasitic stubs meandering lines and converting patch into fractals or by using material of higher relative permittivity substrate[2-3]. However these approaches result in higher Q and reduced bandwidth and radiation efficiency.

For last few years researchers exploiting nanotechnology for antenna on developing new substrate and conductive part of the antenna to overcome size reduction and narrow bandwidth problem [4]. In this paper we demonstrate enhancing bandwidth of antenna by employing silver nanofilm conductive patch instead of bulk patch. Recently F. Urbani and co-workers have successfully fabricated and demonstrated use of conducting nanofilm for enhancement of radiation properties of patch antennas [5]. Instead of copper, they employed aluminium patch on silicon substrate using physical vapour deposition. Their antenna shows ultra wide band response at X-band. Currently, they were investigating the reason for their fabricated antennas wide band width improvement.

II. ANTENNA DESIGN, SIMULATION AND FABRICATION

While developing patch antennas that employing nano materials, fabrication offers challenging job for electrical physical connection of feeding bulk material and nanofilm patch. Usually bulk copper feeding has very low resistance with micron thickness, and, nanofilm has high resistivity and nano thickness. This difference creates difficulties in having reliable electrical contact between bulk and nano material. To overcome above problem, we have selected proximity coupled patch antenna, where patch is electromagnetically coupled to bulk copper feeding, without having physical connection.

A. Antenna Design

The proximity coupled patch antenna geometry is shown in figure 1, consists of a defined radiating metallic circular patch of radius 3.2 mm on the top side of a top dielectric substrate, and metallic ground plane on bottom side of bottom substrate [6].

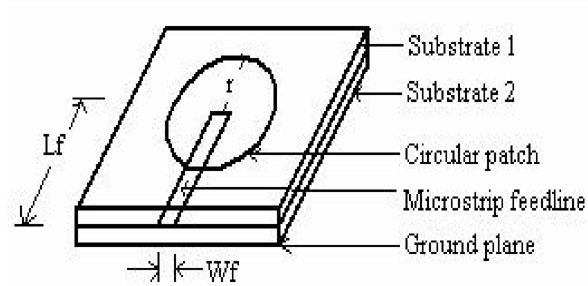

Fig. 1 Geometry of Proximity Coupled Microstrip Patch Antenna

The bottom substrate has a conductive feed line on top with conductive ground plane on other side. The SMA connector terminals are connected to feedline and ground plane. In this work we have selected 25x25 mm FR4 substrate with dielectric constant of 4.4, material loss tangent of 0.0245 and height of 1.6 mm. Since top FR4 substrate is placed on bottom substrate, the total height of the antenna substrate will be 3.2 mm. In this work we have used circular patch for antenna since it occupies less physical space compared to rectangular patch. The advantage of proximity coupled patch antenna is that the matching impedance for frequency resonance can be achieved by controlling the length L_f, width W_f of the feedline and the radius of the circular patch r.

B. Antenna Numerical Simulation

Before antenna fabrication, antenna is simulated for bulk silver patch and silver nanofilm using industry standard IE3D version 14.6 MoM based simulator [7]. For bulk silver patch antenna simulation, 6.3×10^7 S/m is used, where as for silver nanofilm of 30 nm thickness conductivity is calculated using equation given in [8]. For 30 nm thickness the conductivity of silver patch is found to be 2.58×10^7 S/m. The bulk silver patch is modelled using IE3D's thick patch model where as silver nanofilm is modelled using thin patch model.

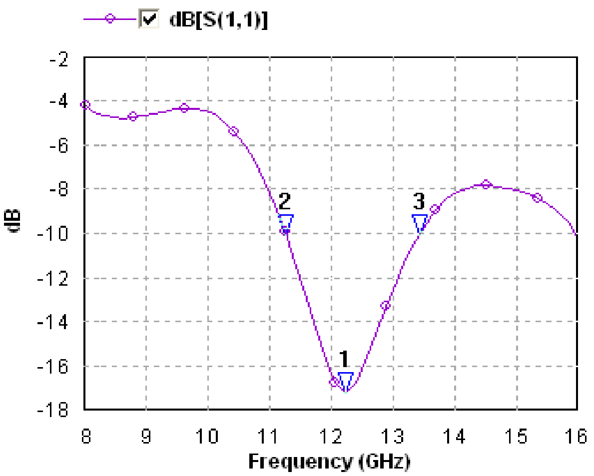

Fig. 2 Simulated response of bulk silver patch antenna: left- resonant frequency vs. Return loss graph, and, right- radiation pattern

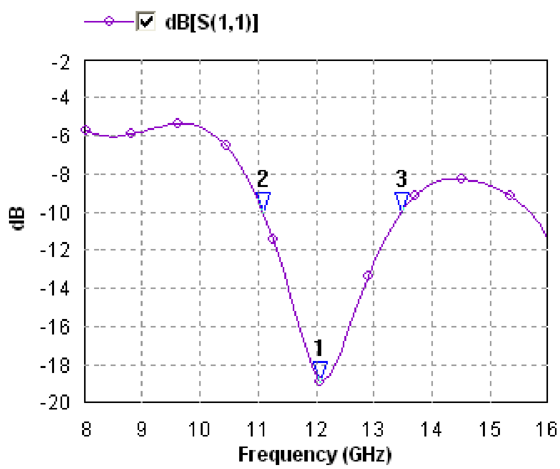

Fig. 3 Simulated response of silver nanofiln antenna: Resonant Frequency vs. Return Loss graph.

Figure 2-3 shows simulated result in terms of resonant frequency vs. return loss for both bulk silver patch antenna and silver nanofilm antenna. The simulation result is listed in table 1 for resonant frequency (f_r), return loss (RL) and bandwidth (BW).

C. Antenna Fabrication

In this work we tried to deposit 99% pure bulk silver available in local market, to a thickness of 30 nm on FR4 substrate using thermally evaporated PVD system, but the deposited nanofilm did not show the conductivity. Hence we have deposited the silver nanofilm of 30 nm thickness on 0.3 mm thickness plastic base and confirmed the continuity. The thickness of the deposited nanofilm is monitored using digital thickness meter attached to PVD system through quartz crystal inside PVD system. The silver nanofilm of radius 2.75 mm deposited on plastic base is pasted on top of upper FR4 substrate using non-conductive araldite standard epoxy adhesive. The feedline of dimensions 15 mm length, and width of 3 mm, is patterned using gum tape and etched using ferric chloride on topside of bottom substrate to excite radiating patch on top substrate. The default copper clad on other side of bottom substrate is kept for

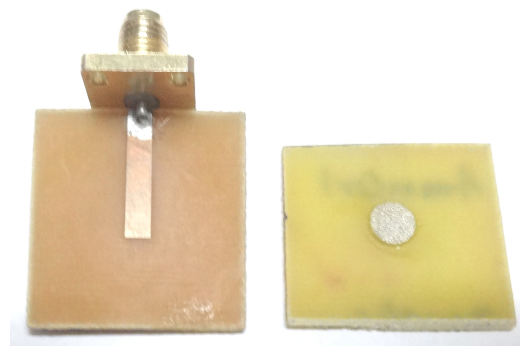

Fig. 4 Fabricated 30 nm thick silver thin-patch proximity coupled antenna. Left: feedline FR4 substrate, right: silver nanofilm patch FR4 substrate

ground plane of the antenna. The fabricated antenna is illustrated in figure 4.

III. Experimental Characterization of Antenna

The experimental characterization of fabricated proximity coupled circular patch antenna that uses silver nanofilm was performed with Rhode-Schwarz vector network analyser model ZVK 1127.8651.60. Frequency is swept from 5 GHz to 16 GHz. The return loss in dB vs. resonant frequency in GHz is illustrated in figure 5. As shown in figure 5, the antenna resonates at 12.1 GHz with a return loss of –20.41 dB. Furthermore the antenna shows a bandwidth of 2.71 GHz at –10 dB reference. This shows enhancement in bandwidth when compared with bulk silver patch simulation result. The results are listed in table 1 for comparison with simulation results.

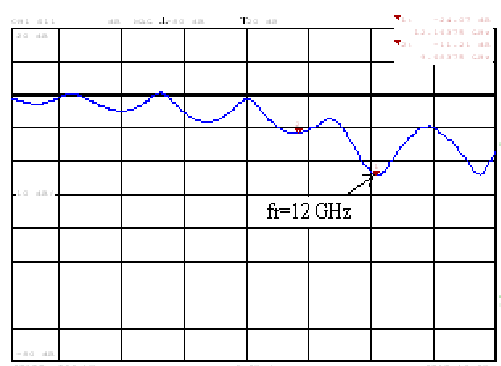

Fig 5. Frequency Response vs. Return Loss graph measured in VNA

TABLE 1. SIMULATED AND FABRICATED ANTENNAS RESULT

Antenna Patch Type	**Radiation Parameters**			
	f_r (GHz)	**RL (-dB)**	**BW (GHz)**	**BW (%)**
Simulated Bulk	12.2	17.17	2.15	17.62
Simulated nanofilm	12.1	18.80	2.38	19.66
Fabricated nanofilm	12.1	20.41	2.71	22.39

IV. RESULTS AND DISCUSSIONS

The proposed antenna is simulated for bulk silver patch and nanofilm silver patch. From simulation result it is found that the percentage bandwidth of nanofilm antenna (19.66 %) is 10 % higher than that of bulk film antenna (17.62 %). As for as fabricated nanofilm antenna is concerned, it is found that the percentage bandwidth (22.39 %) is 20.66 % higher than that of simulated bulk patch antenna (17.62%). In term of return loss, fabricated antenna shows improved impedance matching (RL=-20.41 dB) over bulk patch (RL=-17.17 dB).

From the simulation and experimental results it is observed that as thickness of patch decreases to 30 nm from 17 micron, the bandwidth increases. At nano thickness level the surface resistance of silver nanofilm increases to 1.291Ω/sq from bulk silver patch thickness surface resistance 0.01Ω/sq. This increase in surface resistance decreases 'Q' of the patch thereby increases the bandwidth. Another important factor that contributes bandwidth enhancement is skin depth, as thickness of nanofilm patch (30 nm) is lesser than 0.587 µm skin depth of bulk silver metal at 12 GHz frequency. The other parameters contributing in bandwidth enhancement may be lesser conductive losses, lesser scattering and diffraction effect on nanofilm patch. In bulk patch antenna surface irregularities and diffraction contribute more antenna losses.

Radiation pattern of bulk patch and nanofilm is also studied through simulation. Bulk patch radiation pattern (fig.6) is similar to nanofilm antenna radiation pattern (fig.7). From the similarity in radiation pattern we can conclude that the patch thickness variation does not affect the radiation behaviour of nanofilm antenna.

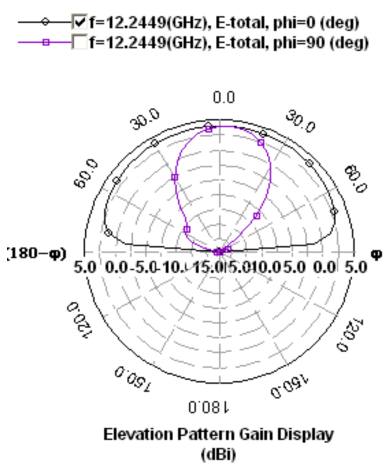

Fig 6. Simulated result: Radiation pattern of bulk silver patch antenna

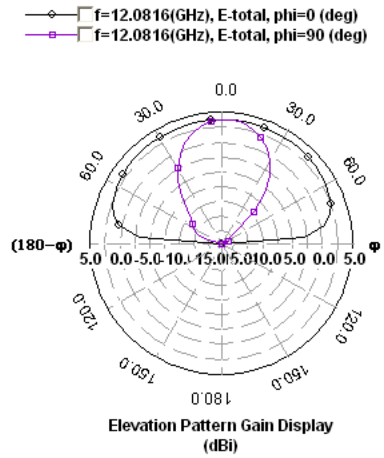

Fig 7. Simulated result: Radiation pattern of silver nanofilm patch antenna

V. CONCLUSIONS

A comparative simulation and experimental characterization of silver nanofilm proximity coupled patch antenna is carried out. The fabricated nanofilm antenna shows excellent bandwidth response compared to bulk film antenna. The higher bandwidth provides higher data rate transmission for applications like high imaging radars, satellite communication, vehicle speed detection, weather monitoring etc. In this experimental characterization proximity fed patch antenna is used as it offers contactless feeding mechanism and electromagnetic coupling between radiating nanofilm and bulk copper feedline. This ensures response of patch is not depending on the reliability of the electrical contact between feedline and nanofilm radiating patch.

With recent advances in nano science, nanotechnology and material engineering, it is possible to deposit or coat radiating metals in nano thickness on dielectric materials. The PVD or CVD deposition system allows us to save noble metals like silver or copper during fabrication of antennas. In conventional lithographic fabrication of antennas, excess metal is being removed from dielectric substrate base.

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