Investigation on Parasitic Semiconductor on Microstrip Patch Antenna Operate at 2.4GHz

Murni Binti Kamarudin
Universiti Teknologi MARA, Malaysia
40450 Shah Alam, Selangor, Malaysia
Email: murnila@gmail.com

Abstract – The design of a rectangular microstrip patch antenna covered with semiconductor material operating at 2.4 GHz for wi-fi application is presented. This paper investigates the semiconductor effect to microstrip patch antenna based on the variety of thicknesses and type semiconductor. The semiconductor material used in this paper such as GaAs, AlGaAs, InGaAs with having difference permittivity.Permittivity for each semiconductor material is difference will indicates a material can become polarized by imposition of an electric field on an insulator (substrate antenna). The antenna are optimized using Computer Simulation Technology (CST) at 2.4 GHz frequency, the antenna will fabricated on FR4 with relative permittivity of 4.8, the substrate thickness is 1.6mm and the copper thickness is 0.035mm respectively. The results of return loss (S_{11}) are gathered and compared based on difference semiconductor material and thickness.

Keywords- Patch antenna, microstrip antenna, semiconductor antenna, reconfigurable antenna.

I. INTRODUCTION

Microstrip Patch Antennas have become highly demands due to their attractive features such as light weight, thin profile, low cost and conformability [1]. Most application, microstrip patch antennas needs dielectric layer to grant protection from heat, physical damage and environment [2]. In addition, the dielectric layer (parasitic semiconductor types) affects the polarization of patch antenna at resonant frequency [3].

When microstip patch antenna stacked with the parasitic semiconductor materials with difference permittivity, carrier mobility which means electron and hole of semiconductor can alter the characterization of the antenna [3]. Due to difference of thickness and semiconductor types, affect the parameters of antenna [4]. Effect of the dielectric layer on the resonant frequency of microstrip antennas also important to verify in oder to improve the antenna design.

The antenna parameters such as antenna gain, voltage standing wave ratio (VSWR) and the polarization can describe behavioral of parasitic semiconductor on the patch antenna. However, the size of rectangular patch antenna can reflect the drifting capability of the electron and holes on the surface cover by parasitic semiconductor [5].

The mains objectives of this project are to identify the suitable semiconductor material based on the permittivity values and thickness of parasitic semiconductor whether is acceptable to integrate with an antenna. If the radiated signal from the multilayer (covered) patch antenna achieve the standard parameter antenna, this concept is acceptable

II. PARASITIC RECTANGULAR MICROSTRIP PATCH ANTENNA DESIGN

Two rectangular patch antennas design in this paper which is microstrip patch antenna multilayered with the parasitic semiconductor and without parasitic semiconductor. The performance of the microstrip patch antenna depends on its dimension. Depending on the dimension the resonant frequency, radiation efficiency, directivity, return loss and other related parameters are also influenced [6]. All the formula for determine the size of patch antenna as below [7].

Width of patch, w

$$\boldsymbol{W} = \frac{Vo}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \qquad (1)$$

Effective dielectric, ε_{reff}

$$\boldsymbol{\varepsilon_{reff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{12h}{W}\right)^{-\frac{1}{2}} \qquad (2)$$

Extended excremental length of patch, ΔL

$$\Delta \boldsymbol{L} = 0.412h\left(\frac{\varepsilon_{reff} + 0.3\left(\frac{W}{h}+0.264\right)}{\varepsilon_{reff} - 0.258\left(\frac{W}{h}+0.8\right)}\right) \qquad (3)$$

Actual length of patch,

$$= L_{eff} - 2\Delta L \qquad (4)$$

$$= \frac{C}{2fr\sqrt{\varepsilon_{reff}}} - 2\Delta L$$

Length of substrate

$$\boldsymbol{L_S} = 6h + L \qquad (5)$$

Width of substrate

$$\boldsymbol{W_S} = 6h + W \qquad (6)$$

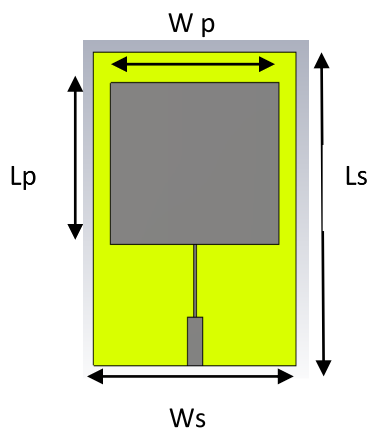

Figure 1: Overview patch antenna without parasitic semiconductor

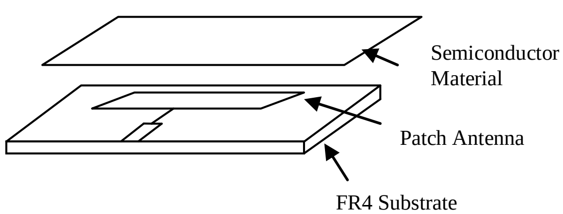

Figure 2: Overview patch antenna with parasitic semiconductor

The dimensions of both antennas are shown in table 1 below;

Table 1: Dimensions of rectangular patch antenna with and without parasitic semiconductor

Size of antenna (mm)	After Optimization	After multilayered with parasitic semiconductor
Length of substrate (Ls)	52.00mm	52.00mm
Length of patch (Lp)	26.90mm	27.20mm
Width of substrate (Ws)	38.00mm	38.00mm
Width of patch (Wp)	31.50mm	31.00mm

The optimized sizes for the microstrip rectangular patch antenna are stated in table 1. Size of patch width (Wp) antenna has a minor effect on the resonant frequency and the radiation pattern of the antenna. A larger patch width increase the power radiated, increase bandwidth, increased radiation efficiency and decrease the resonant frequency [6].

III. SIMULATION RESULTS

A. Basic patch antenna without parasitic semiconductor

The antenna performances were investigated through simulation and measurement process. Microwave Studio Technology (CST) is used to obtain the simulation results whereas the measurement results used Vector Network Analyzer (VNA). These results are shown as below;

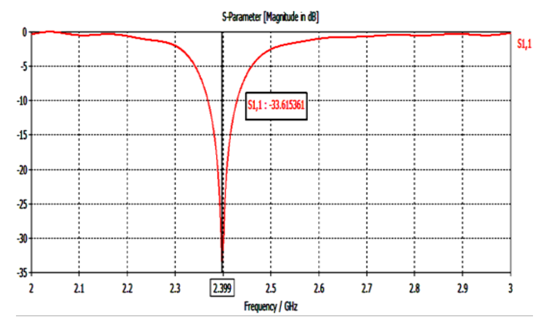

Figure 3: Return loss (S_{11}) result for rectangular patch of 2.4 GHz.

Table 2: Performance analysis for basic patch antenna without parasitic semiconductor layer.

Performance Parameters	Values
S11	-33.6154dB
VSWR	1.0426
Gain	4.3460dB
Bandwidth (%)	14.4920

Fig.3. represent the simulation results for return loss (S_{11}) for rectangular microstrip patch antenna without any layer of parasitic semiconductor. It can be seen that S_{11} antenna follow the important requirement of design antenna which is the return loss is must less than -10 dB. The S_{11} value is -33.6154 dB at 2.4 GHz resonant frequency. Performance analysis for basic patch antenna without any parasitic semiconductor layer shows as table 2. All desired parameters are satisfied follow the antennas requirements.

B. *Patch antenna with parasitic semiconductor layers.*

The simulation design starting multilayered with various parasitic semiconductor materials such as GaAs, InGaAs, AlGaAs and GaP. The material is choosing based on the Light Emitting Diode (LED) resources guided by the difference permittivity values. The overall structure of the antenna consists of ten difference layers of thickness are optimized one by ones begin from 0.1µm to 1.0µm. The reason changes the thickness and varieties of semiconductor are to observe the effect of permittivity values on the performance rectangular patch antenna.

I. *Multilayered by GaAs*

The design has been started at early stage by cover the rectangular microstrip patch antenna with GaAs permittivity, $\varepsilon_r = 12.94$. Some of parametric study has been done to analyze the effects that occur in the antennas performance such as the gain, directivity and return loss (S_{11}). From the study, the best antenna performance can be seen through the antenna gain and the reflection coefficient. The width and length of the substrate has been keep constant with the similar dimension to know the effect when the difference type of parasitic semiconductor and difference thickness are placed above the patch antenna.

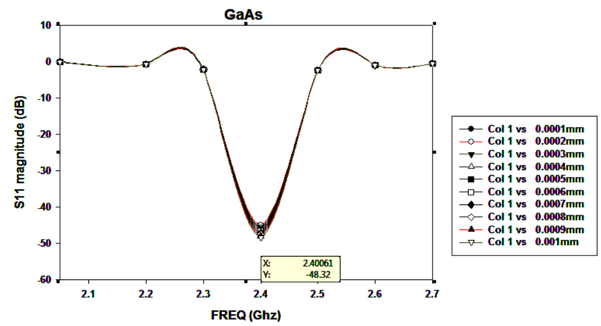

Fig 4 : S_{11} result performance antenna multilayer with GaAs

Fig. 4 indicates the simulation result for return loss (S_{11}) based on GaAs material. The results shows various of thickness not given very much difference from each other, by the way one of the thickness gives the best result which is -48.3200 dB at 1.0µm thickness and the VSWR contribute 1.008 at the operating frequency 2.4 Ghz .It indicates the matching between feeding point and radiating patch. The satisfied values for VSWR(VSWR<2).

II. *Multilayered by AlGaAs*

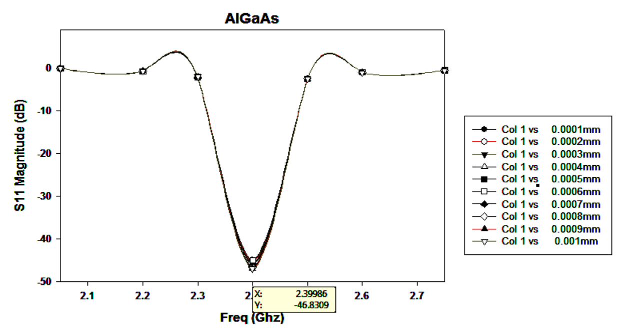

Fig 5 : S11 result performance antenna multilayer with AlGaAs .

From Fig.5, it depicted that the result S_{11} for AlGaAs, permittivity $\varepsilon_r = 15.524$ which is higher than GaAs permittivity. It can seen that the S_{11} is best when rectangular patch antenna multilayered by 1.0µm thickness with value of -46.8309 dB.

III. Multilayered by GaP

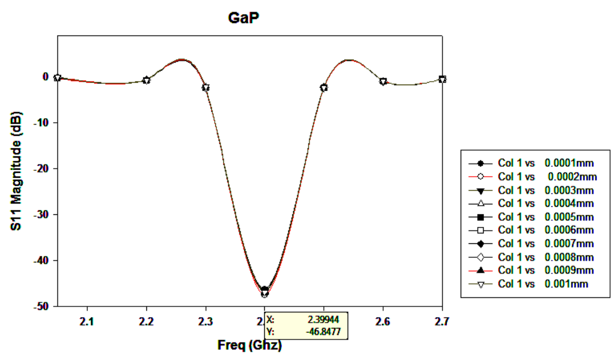

Fig 6: S11 result performance antenna multilayer with GaP

Fig. 6 represents the return loss (S_{11}) for the difference thickness of the parasitic GaP, $\varepsilon_r = 11.10$. The best S_{11} parameter indicates -46.8770dB with thickness at 0.9µm. These S_{11} value meets the requirement of less than – 10dB cut off. Based on 0.9µm thickness, it produces 19.75% bandwidth compare to AlGaAs which is 19.50% is calculated refer to the return loss at -10 dB. AlGaAs have a narrow bandwidth rather than GaP.

IV. Multilayered by InGaAs

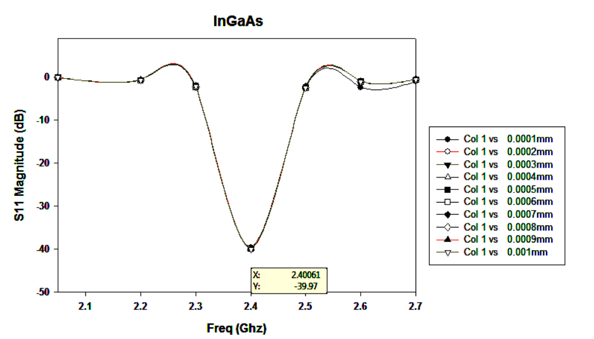

Fig 7 : S11 result performance antenna multilayer with InGaAs.

From the result shown in Fig.7, return loss (S_{11}) with InGaAs with permittivity $\varepsilon_r = 13.90$ for different thickness of parasitic semiconductor. From variety of thickness, there are found that the antenna multilayered by 1.0µm produced the best return loss which is -39.9700dB. Power relations and the reflected power also described as return loss (S_{11}). S_{11} is below -10 dB would indicate 90% of average power transmission.

The simulation results from the fig. 4-7 indicate return loss values for all the parasitic semiconductor and thicknesses. Simulated results of S_{11} for impedance bandwidth at -10 dB are best with parasitic GaAs where the total reflection current caused by conduction electron, drifting of electrons, and holes from the patch to the semiconductor materials. In addition, it can be seen that, as the layer of thickness parasitic material increase, the S_{11} values also increase at operating frequency 2.4 GHz respectively. In conclusion, the thicker the thickness of parasitic material multilayered with patch gives impact to the antenna performance.

V. PERFORMANCE ANALYSIS BETWEEN THE BEST FOUR TYPES OF SEMICONDUCTOR MATERIALS.

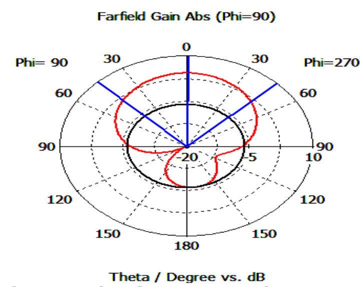

Fig 8: Basic radiation (polar plot) pattern without any parasitic semiconductor material.

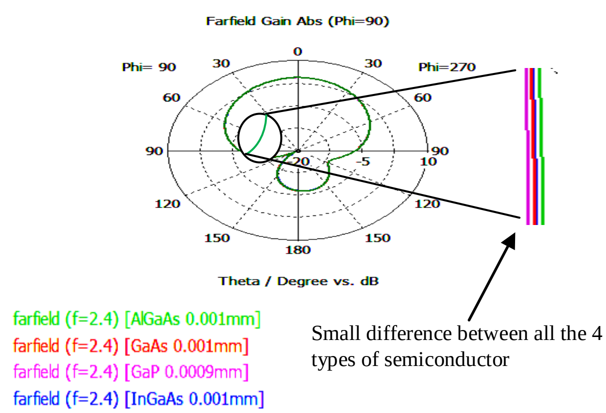

Fig 9 : Radiation(polar plot) pattern for patch antenna covered with GaAs, AlGaAs, InGaAs and GaP.

Fig. 8 and Fig.9 depicts the radiation pattern for the patch antenna without parasitic semiconductor layer and with parasitic semiconductor layer. From the fig. 9 shows combination of radiation pattern based on four types of semiconductor material. The result show the dissimilarity of permittivity values not given very much difference for it radiation. For both figures, it can be seen that, the major lobe strongly radiated and the angular width is 89.7°, with side lobe level of -10.7 dB.

The beam width of an antenna is usually measured as the aperture flanked by the half-power points (3dBdown) of major lobe.

Table 3 : Comparison Result

Performance parameter	GaAs	AlGaAs	InGaAs	GaP	Witout semicon -ductor
Simulated Gain (dB)	4.329	4.330	4.319	4.321	4.346
Directivity (dBi)	5.715	5.718	5.719	5.715	5.695
VSWR	1.008	1.009	1.020	1.009	1.043
Zin	50.52	50.65	50.499	50.74	51.849
Bandwidth (%)	25.46	19.50	31.33	19.75	19.25

Farfield Gain Abs (Phi=90)

A comparison of all the antenna parameter is presented in Table 3. The rectangular patch antenna with parasitic semiconductor produced batter performance compared to rectangular patch antenna without parasitic semiconductor in term of return loss (S_{11}), gain, directivity, VSWR, input impedance (Zin) and bandwidth. Table above stated that, the reduction gain happen when patch antenna covered by the semiconductor materials, whiles the bandwidth and VSWR increase the performance when multilayer by parasitic semiconductor. The VSWR values signify the degree of mismatch between a transmission line and its load. Moreover, higher gain is needed for the antenna to operate effectively that show the power of antenna can be radiated at the surface. For input impedance (Zin) of the antenna is 50Ω, therefore all the Zin values above are satisfied. It shows the quarter wave line matching. Through the table above, it can be said that parasitic semiconductor not much affected the parameter antenna.

VI. RESULTS MEASUREMENT AND DISCUSSION

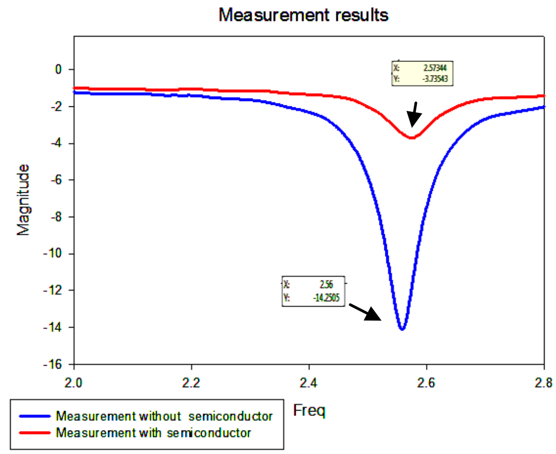

Fig 10: Mesurement result of S_{11} for rectangular patch antenna with and without parasitic semiconductor

Fig.10. Represents the measurement result of Return Loss (S_{11}) for rectangular microstrip patch antenna with and without parasitic semiconductor. It is shown that resonant frequency of the antennas is slightly shifted. The rectangular microstrip patch antenna without parasitic semiconductor resonate at 2.57 GHz which is shifted to the right by 160 MHz while the rectangular microstrip patch antenna with parasitic semiconductor resonate at 2.57 GHz which is shifted to the right by 180 MHz. Normally, the differences between two readings are due to interference or disturbance that affects the substrate in open air environment. Other than that, it is also occur due to corrosion of copper during fabrication process. However, for microstrip patch antenna without parasitic semiconductor produce good return loss (S_{11}) less than -10 dB.

The antenna with parasitic semiconductor generate less than -10 dB because of due the process of Sol- Gel Spin Coat (SGSC) the speed of spinning is limited because of model antenna is a little heavy, so the machine cannot spinning at the proposed speed which is at least 3000 rpm to ensure all the parasitic semiconductor solution spread evenly. During SGSC process using 1500 rpm that cause the spread of solution not evenly contribute the difference thickness at the patch antenna and produce the instable results. SGSC process also use ZnO with permittivity ε_r = 10.40 which is lowest values compare to the other four type of parasitic semiconductor material that have simulated. This is because, material should use through SGSC process do not comes as expected.

To overcome this problem, need to reduce weight of model antennas which means choice the lower thickness of substrate and high of resonant frequency. These ways can reduce the size and weight of antennas.

V1. CONCLUSION AND RECOMMENDATION

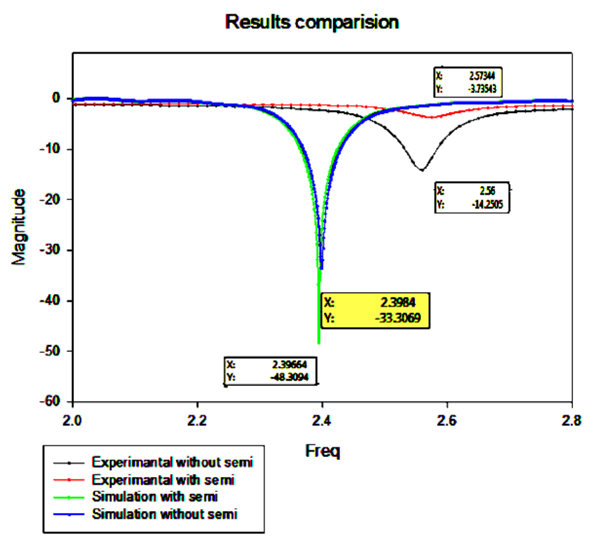

Fig 11: Results simulation and measurement with and without parasitic semiconductor

In this paper, the rectangular microstrip patch antennas covered with parasitic semiconductor material with difference dielectric layers have been simulated, fabricated and measured. The performance is compared based on type of parasitic semiconductor refer to dielectric constant values and the thickness of material. The results shows that not all condition when increasing values dielectric constant are appropriate to improve the performance of antenna. The selection of the type of semiconductor material and thickness layer plays an important role in order to improve the performance of the antenna. Fig. 11 depicts results simulation with and without parasitic semiconductor on the return loss (S_{11}) values. S_{11} without semiconductor is -33.3069 dB while with semiconductor is -48.3094 dB . For measurement, S_{11} with parasitic semiconductor not achieve the parameter antenna cause of many factor such as SGSC process and the fabrication process. From the analysis it is conclude that the designed microstrip patch antenna is better when combine with GaAs material with 1.0µm thickness.

Some improvements can be done to increase the performance of antenna in future research. The antenna can be design using difference shape and dimension. Difference type of antenna and difference ways cover the layer of antenna might also affect the antenna performance. Using Chemical Vapor Deposition (CVD) technique is also encouraged to multilayer the antenna.

REFERENCES

[1] Bahl, Inder J., Prakash Bhartia, and Stanislaw S. Stuchly. "Design of microstrip antennas covered with a dielectric layer." *Antennas and Propagation, IEEE Transactions on* 30.2 (1982): 314-318.

[2] Bhattacharya, A. K., and T. Tralman. "Effect of dielectric super-strate on patch antenna'." *Electron. Lett* 24 (1988): 356-358.

[3] Kumar, K. Praveen, et al. "The effect of dielectric permittivity on radiation characteristics of co-axially feed rectangular patch antenna: Design & Analysis

[4] Bahl, I. J., and Stanislaw S. Stuchly. "Analysis of a microstrip covered with a lossy dielectric." *Microwave Theory and Techniques, IEEE Transactions on*28.2 (1980): 104-109.

[5] Milligan, Thomas A. *Modern antenna design*. John Wiley & Sons, 2005.

[6] Garg, Ramesh. *Microstrip antenna design handbook*. Artech House, 2001.

[7] Huque, Md Tanvir Ishtaique-ul, et al. "Performance Analysis of Corporate Feed Rectangular Patch Element and Circular Patch Element 4x2 Microstrip Array Antennas." *International Journal of Advanced Computer Science & Applications*2.7 (2011).