Proceedings of Asia-Pacific Microwave Conference 2006

InP Aperture Coupled Patch Antenna for Millimeter-wave/Photonic Integrated Circuits

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***Abstract* — A printed antenna is presented that is realized on an Indium Phosphide wafer. The antenna uses aperture coupling between a CPW feed line and a parasitic patch, with the substrates layers in a *hi-lo* configuration. The antenna exhibits a measured impedance bandwidth of 12%, and a gain of 6±2 dBi within this bandwidth. Applications for this efficient, broadband InP based antenna include MMIC and OEIC systems and sub-systems.**

***Index Terms* — Microstrip antennas, MMICs, monolithic integration, Indium Phosphide.**

I. Introduction

Antennas that can be easily integrated with microwave and optical components could provide significant benefits to millimeter-wave fiber wireless applications [1]. A fully integrated fibre fed wireless transceiver has the potential to realize small and inexpensive antenna basestations. Active integrated antennas [2], where amplification is provided at the antenna site, is another application where directly integrated antennas can provide neat and cost effective solutions.

The low profile, planar architecture of printed antennas makes them a sensible candidate for direct integration with microwave and optical systems. Active microwave and optical devices are fabricated from semiconductor materials (for example: Gallium Arsenide or Indium Phosphide (InP)) which have a high value of permittivity ($\varepsilon_r \approx 10$). Most conventional printed antenna architectures perform poorly on high permittivity substrates. Common performance deficiencies include a narrow bandwidth, and a deformed radiation pattern and diminished radiation efficiency due to excessive surface wave excitation. This is reflected in the literature with many MMIC/OEIC integratable antennas (for example [3]) exhibiting narrow bandwidth and/or indicators of low efficiency. A stacked antenna structure which uses a combination of a high permittivity feed substrate and a low permittivity antenna layer [4] displays excellent bandwidth and radiation performance. A coplanar waveguide (CPW) fed aperture stacked patch (ASP) [5] which follows the same principles as [4] also exhibits wideband efficient radiation. Wide band antenna elements are desirable to ensure that the system bandwidth is not limited by the antenna.

Optoelectronic integrated circuit (OEIC) modules [6] diminish parasitic effects associated with interconnections (such as wire bonding or butt-coupling). CPW transmission structure may be employed for OEICs so only single sided wafer processing is required, eliminating the need for vias or plated through holes. An InP material system can potentially realize all of the active and passive devices required for an integrated fiber-wireless base station. Hence, an OEIC based on InP can produce cost effective and reliable system/sub-system modules.

In this paper, a broadband millimeter-wave antenna suitable for integration with microwave and optical circuits is fabricated on an InP wafer. The antenna is a CPW fed aperture coupled patch (ACP) geometry, utilizing the broadband efficient design principles of [4] and [5].

II. InP Antenna Structure

Figure 1 portrays the configuration of the InP CPW fed ACP. The 350 µm thick semi-insulating InP:Fe wafer has a resistivity in excess of 10^7 Ω.cm, and a relative permittivity of approximately 12.4. A conducting layer is formed on the InP wafer by depositing a Ti-Ni-Au seed layer to ensure adequate adhesion. The CPW feed line and coupling aperture are then patterned using photolithography, and electroplated to a thickness of 8 µm. An acrylic carrier is used to support the InP:Fe wafer and to enable the attachment of a coaxial K-connector. Back radiation can become a concern when using resonant aperture coupling to enhance the bandwidth (as seen in [5]). To counter some of this unwanted back radiation, the coupling aperture of the InP CPW fed ACP resides over a 1 mm deep well of RF absorber cut into the carrier.

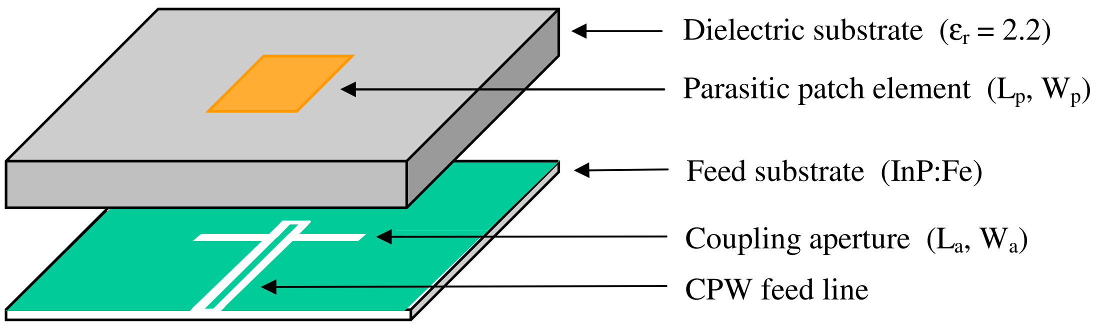


Fig. 1. Schematic of the InP CPW fed Aperture Stacked Patch Antenna. (dimensions: L_p = 2.5 mm, W_p = 1 mm, L_{a}, = 2 mm, W_a = 0.06 mm)

A 0.762 mm thick Rogers RT/Duroid 5880 substrate with a parasitic patch element etched on the top side is stacked centrally over the aperture on the InP wafer. The resonant aperture is mutually coupled to this parasitic patch element, to produce a broad bandwidth. The antenna dimensions are given in the caption of Figure 1. The *hi-lo* architecture [5] which produces an efficient, broadband antenna, is formed by the combination of the high permittivity InP:Fe wafer and the low permittivity RT/Duroid 5880 substrate. Previous *hi-lo* antenna configurations have not incorporated semiconductor materials like the antenna proposed here.

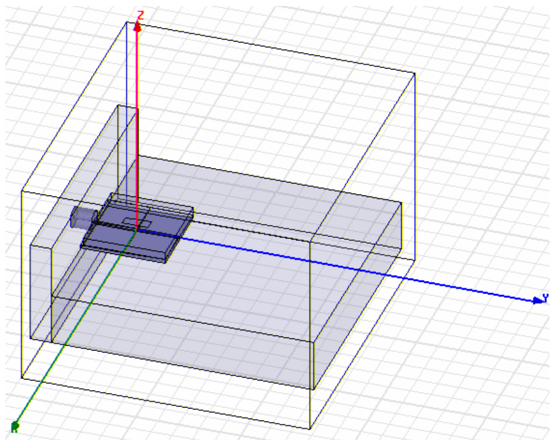


Fig. 2. HFSS simulation layout of the InP CPW fed ACP antenna mounted on an acrylic carrier.

III. Simulated Results

The antenna and carrier structure was simulated using the Ansoft HFSS simulation package. A screen shot of the simulation layout is displayed in Figure 2. The theoretical return loss is shown in Figure 3. The InP antenna exhibits an impedance bandwidth of 13.8% for VSWR < 2.

Figure 4 depicts the simulated far field radiation patterns at 34 GHz in both the H-plane (Figure 4(a)) and E-plane (Figure 4(b)). The E-plane pattern exhibits a large sidelobe level at about 70 degrees from broadside, and an undulant main beam. This is a consequence of radiated field reflecting off the brass plate used to attach the coaxial connector on the side of the acrylic carrier.

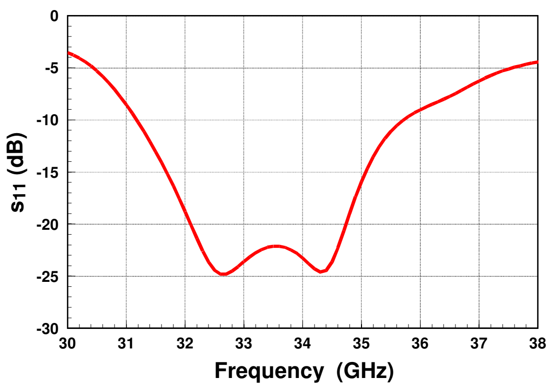
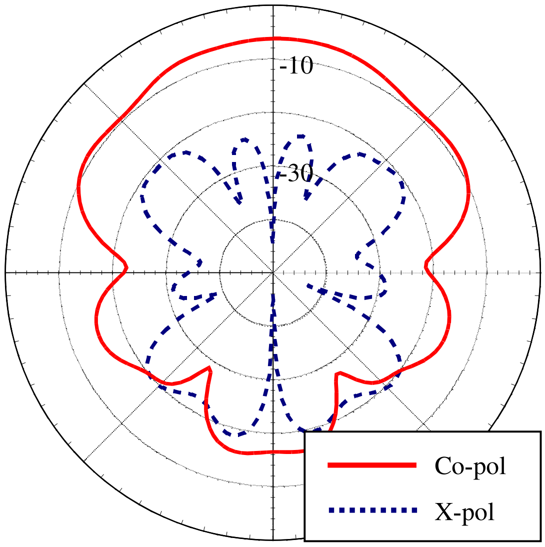
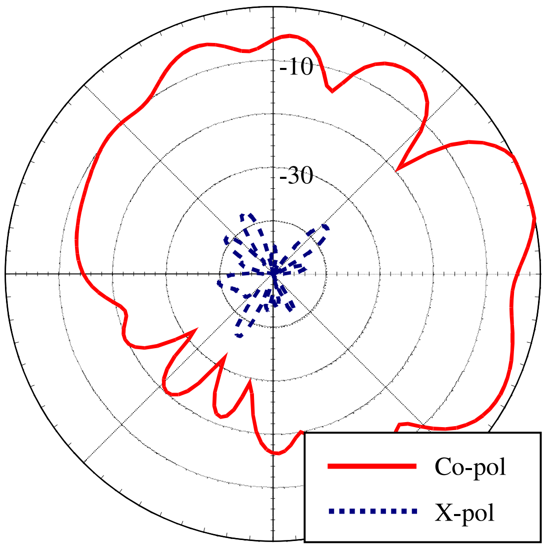


Fig. 3. Simulated s_{11} of the InP CPW fed ACP antenna with an acrylic carrier.



(a)



(b)

Fig. 4. Simulated radiation patterns of the InP CPW fed ACP antenna at 34 GHz (a) H-plane (b) E-plane.

IV. MEASURED RESULTS

A prototype InP CPW fed ACP was fabricated to validate the simulation results. A photograph of the processed InP wafer mounted on the acrylic carrier is given as Figure 5. The measured return loss of the InP CPW fed ACP can be derived from Figure 6. The antenna exhibits an impedance bandwidth of 11.8% for VSWR < 2. The measured results show a minor frequency shift and a slightly narrower bandwidth than the simulated results in Figure 3. This is due to uncertainty in the value of the permittivity for both the InP and the acrylic carrier at millimetre-wave frequencies, and minor misalignment of the antenna dielectric substrate. However, the authors believe that this antenna exhibits the widest reported bandwidth for an antenna on InP. A further enhancement of bandwidth may be achieved by stacking an additional patch element over the InP CPW fed ACP structure, as was done in [5].

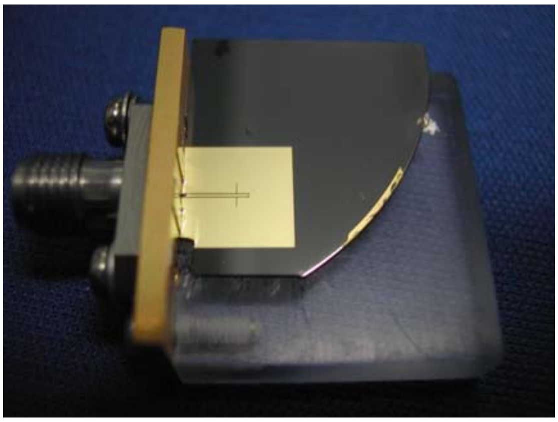


Fig. 5. Photograph of the processed InP substrate mounted on an acrylic carrier.

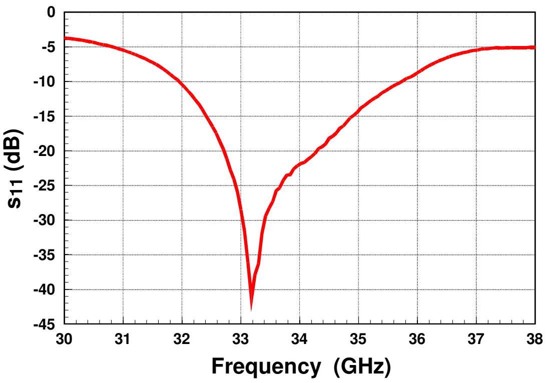


Fig. 6. Measured s_{11} of the InP CPW fed ACP antenna.

The far field co-polarized radiation patterns were measured at 34 GHz and plotted in Figure 7. The radiation patterns are jagged in appearance due to the manual measurement method using a millimetre-wave propagation table. Received radiated power readings were taken every three degrees in both the H-plane and the E-plane. As was the case with the simulated E-plane pattern of

Figure 4(b) a large sidelobe level is present, due to the brass plate used to attach the coaxial connector. However the measured results show that this sidelobe is at a maximum at about 95 degrees from broadside.

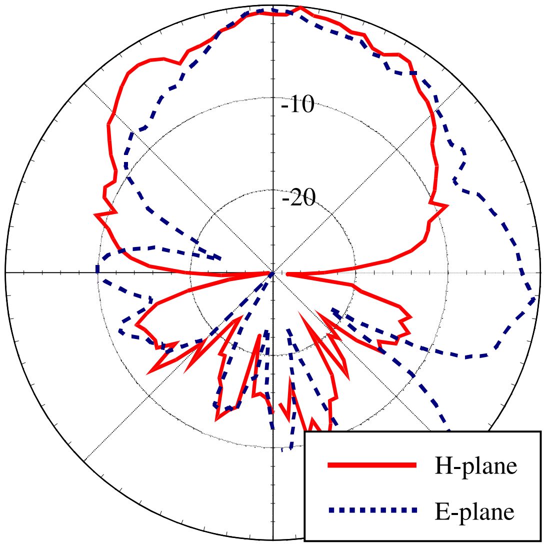


Fig. 7. Measured radiation patterns of the InP CPW fed ACP antenna at 34 GHz.

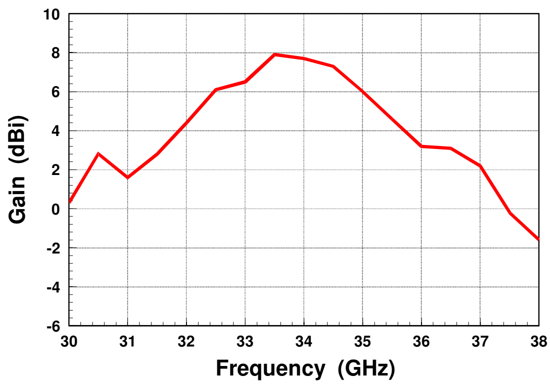


Fig. 8. Measured gain of the InP CPW fed ACP antenna versus frequency.

Figure 8 displays the measured gain of the InP ACP. The gain peaks at approximately 8 dBi close to the centre of the impedance bandwidth. The gain then falls off towards the edges of the antenna bandwidth, and declines sharply for frequencies past the bandwidth edges. This implies that there is significant surface wave generation outside the impedance bandwidth of the antenna. The coupling between the aperture and the parasitic patch element is diminished outside the antenna bandwidth, allowing the energy to become trapped in the InP wafer. Another indication of this surface wave generation is the return loss levelling off to 4 to 5 dB past the bandwidth edges, as seen at 30 and 38 GHz in Figure 6.

VI. Conclusion

A CPW fed aperture coupled printed antenna fabricated using an InP feed wafer is presented in this paper. The antenna exhibits a measured gain of 8 dBi and an impedance bandwidth of approximately 12%. The wide bandwidth and high gain are due to the *hi-lo* permittivity substrate configuration. This antenna provides an efficient solution for integrated millimeter-wave fiber wireless modules, as well as other communications applications requiring small broadband antenna sub-systems.

Acknowledgement

The authors wish to acknowledge the assistance of Mr Paul Jones in the construction of the InP antenna and carrier.

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