Silicon Based Reconfigurable Antennas

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Abstract **— Efforts are under way to revolutionize antenna technology and to increase their functionality and capabilities by implementing fast reconfiguration schemes. Sarnoff Corporation (Sarnoff) has developed a novel silicon based concept for true reconfiguration based on the creation of metallic-like conductivity plasma islands that are driven by dc current. These plasma islands can be precisely formed and controlled using today's high resolution silicon technology, and are utilized to dynamically form plasma holograms for holographic antennas, enabling frequency hopping, beam steering and shaping without the complexity of feed structures, thus providing the performance and capabilities of a phased array without their price.**

I. INTRODUCTION

Recently there has been a tremendous effort in developing reconfigurable antennas, where an antenna's aperture is dynamically modified to perform different functions at different times. The antenna aperture can then be specifically tailored to the application at hand greatly increasing speed and efficiency, while maintaining a high degree of flexibility. Various proposed schemes under the RECAP* program support run-time reconfigurability or partial reconfigurability using MEMs. Sarnoff, as part of the RECAP program, is developing an exciting innovative alternative approach for the implementation of a dynamic full aperture reconfiguration, where a reconfigurable antenna can be implemented by varying the conductive pattern on the surface of the antenna structure.

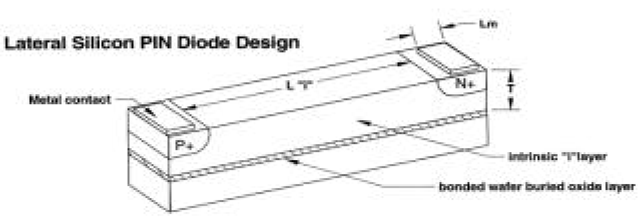

Fig. 1. SPIN device cross-section. Intrinsic region "I" length is "L", Metal pads Length "Lm", I region thickness is "T". This is a bonded wafer where a buried oxide layer is used for carrier confinement.

II. INNOVATIONS

Sarnoff has a newly developed surface PIN (SPIN) device to dynamically define plasma regions with sufficient conductivity (see Fig. 1). The SPIN device structure is optimized (see Table I) to achieve relatively high metallic-like conductivity under dc control. Injecting dc currents into precisely defined channels on the silicon surface (created by cascading many of these SPIN devices that are implanted in a high resistivity silicon) creates plasma regions (domains) with relatively high conductivity [1-3]. The locations and shapes of these defined channels can be precisely controlled over the whole processed silicon wafer using today's mature silicon technology.

Figure 2 shows an array structure with an x-y grid that can be implemented using SPIN devices with its dc bias circuits. Here the grid under dc control can be reconfigured to "paint" various antenna structures such as dipoles, folded dipoles, and yagi antennas. This generic concept can also be utilized to dynamically reconfigure holograms for holographic antennas [4], thus achieving the performance of a phased array antenna without the cost of one.

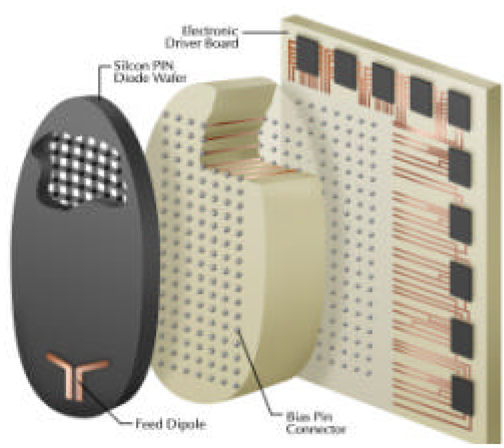

Fig. 2. Plasma xy grid defined on the surface of a multi-layer silicon wafer with an integrated feed. The form, shape and function of these plasma islands are controlled by DC bias PIN connections.

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TABLE I
DEVICE PROCESSING REQUIREMENTS AND DESIGN APPROACHES

Requirement	Design Approach
Injected carrier density > 10^{18} cm^{-3} injected carrier plasma extends across “I” layer	Make I region length equals to the carrier diffusion length (Approx. 250 µm)
Minimize required drive current	Reduce the thickness of the active region using bonded wafers with buried oxide isolation
Make device disappear in “off” state	Reduce length of the metallic islands
Lateral isolation between devices for spatial resolution of pattern	Maintain diode spacing > recombination length, or use trench isolation

III. DEVICE OPTIMIZATION

Figure 1 shows a cross-section of a SPIN device, where carriers are highly confined to the uppermost top surface. The device dimensions, doping concentrations, and boundary layers are optimized to trap carriers in well defined channels approaching high concentration levels exceeding $10^{18}/cm^3$ with minimal dc drive current. The thickness of these plasma islands is within 2-3 skin depths and separated from the device body by an oxide layer. The metallic-like conductivity with $10^{18}/cm^3$ carrier levels led to an efficiency of over 75% an X-band $\lambda/2$ dipole antenna being achieved. Meanwhile, lateral isolation between neighboring devices is enhanced by the utilization of trenches.

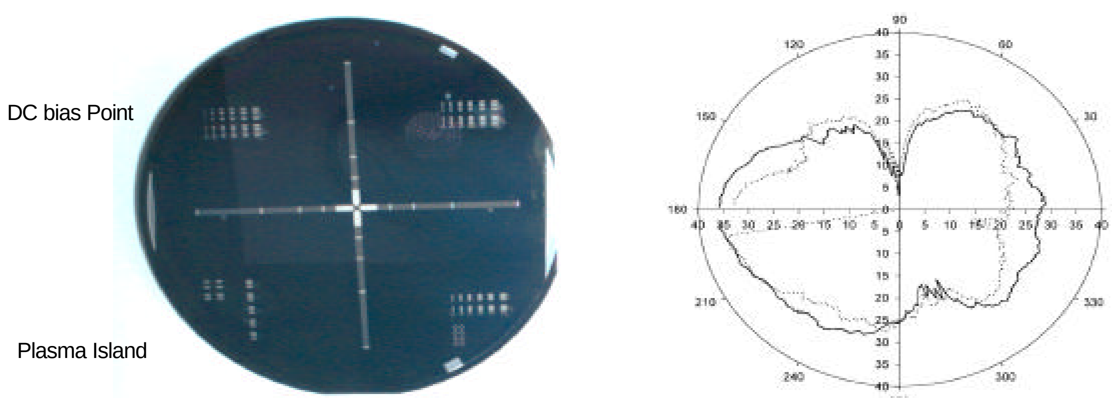
SPIN devices DC power requirements are commensurate with the devices’ lateral dimensions and their number. Simple calculations indicate that 4 W are required for an L-band, relative to 0.4 W for X-band $\lambda/2$ dipole antennas. Holographic antennas with 10 dB gain would require about 16 W at X-band, and 4 W at 35 GHz.

IV. PROOF OF CONCEPT EXPERIMENT

Sarnoff has fabricated a reconfigurable dipole antenna using SPIN devices as a proof of concept experiment. The fabricated dipole antenna can be controlled (reconfigured) using dc current, to cover over an decade bandwidth (2-20 GHz). The dipole antenna is comprised of 5 segments (as seen in Fig. 3a), and can be utilized to hop from one operating frequency range to another allowing full decade coverage. The measured radiation pattern at 4 GHz is shown in Fig. 3b as an example. Fig. 4a is the measured return loss for a plasma radiator made out of three segments and assembled as a mono-pole (shown in Fig. 4b) when configured for four operating frequencies. These results confirm plasma antenna radiation.

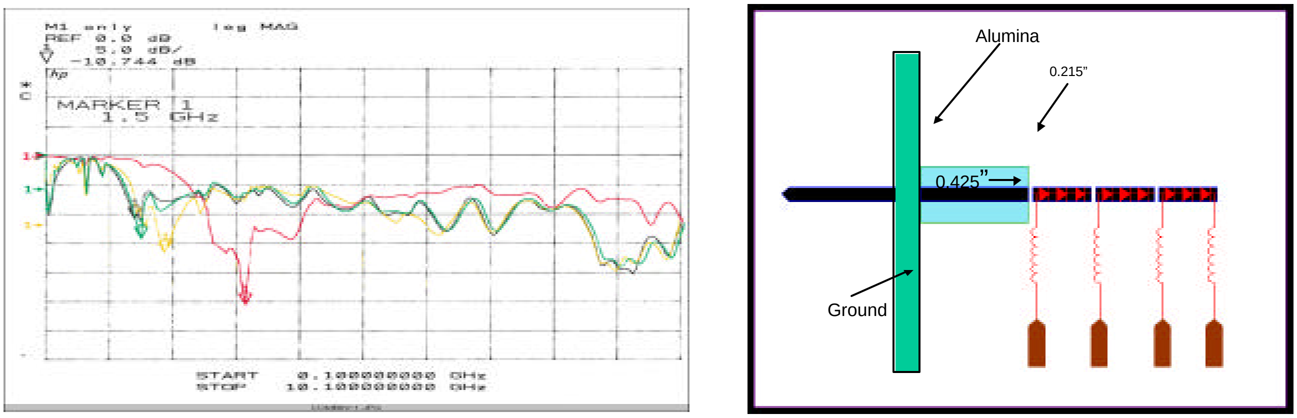
V. HOLOGRAPHIC ANTENNA APPLICATION

The developed conductive grid can be utilized to fabricate various antenna structures. Holographic antennas are an excellent utilization of this grid array structure. Fig. 2 shows an integrated antenna/feed structure where the feed generates the required reference wave. The radiation pattern is due to the interference between the reference wave (surface wave) and the



(a) (b)

Figure 3. (a) Crossed dipole defined using plasma islands. Metal contacts bridging these plasma islands to allow for carrier injection. (b) The radiation pattern of the plasma dipole at 4GHz, relative to that of the dipole in the off-state.



(a) (b)

Fig. 4. (a) Stretching the dipole length allows frequency hopping. The metallic mono-pole operates at 3.25GHz, turning on the first section shifts the operating frequency to 1.95GHz, while further stretching shifts the operating frequency to 1.6GHz, then 1.5GHz. (b) A sketch of the assembled mono-pole.

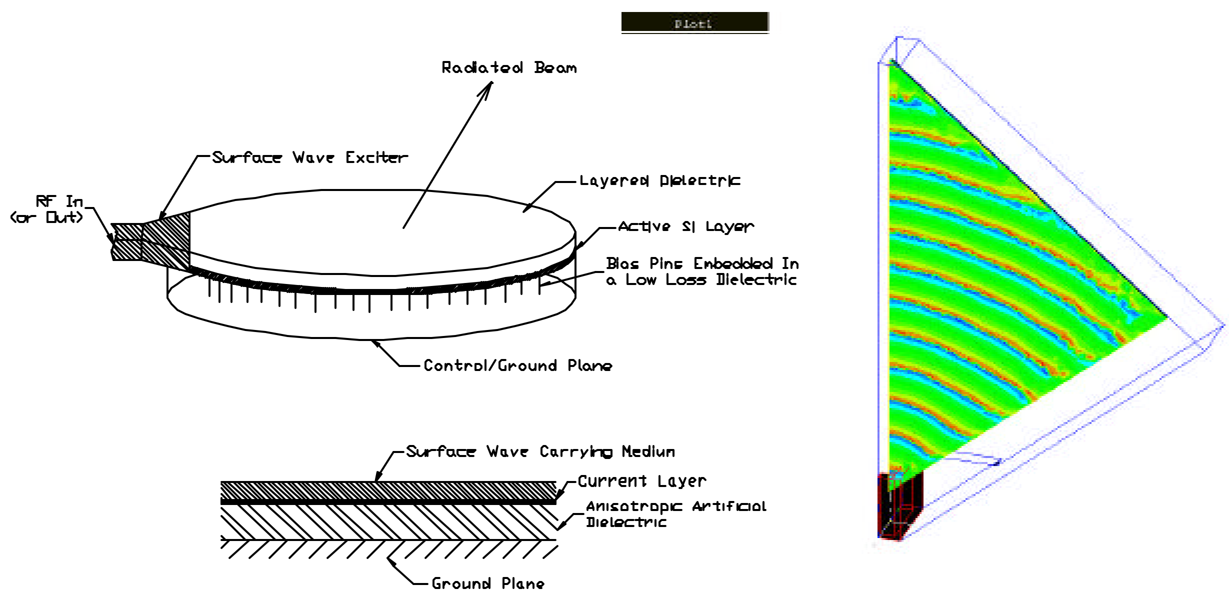


Fig. 5. An EM model of the multi-layered structure, and the HFSS results.

metallic-like fringes of the hologram. Fig. 5 shows a HFSS simulation of the surface wave excitation feed structure. The surface wave leakage due to the metallic-like fringes leads to the object creation, i.e. the radiation pattern [4]. Extensive EM analysis and modeling is underway to accurately predict the radiation patterns.

A pre-stored or developed on the run holograms can be used to increase the capabilities and expand the functionality of these holographic antennas. They can be used for beam steering functions such as searching or tracking. Fig. 6 shows the anticipated discretization errors due to the use of binary level grid-defined holograms, where the error is minimal due to a small pixel size of 250µm x 250 µm.

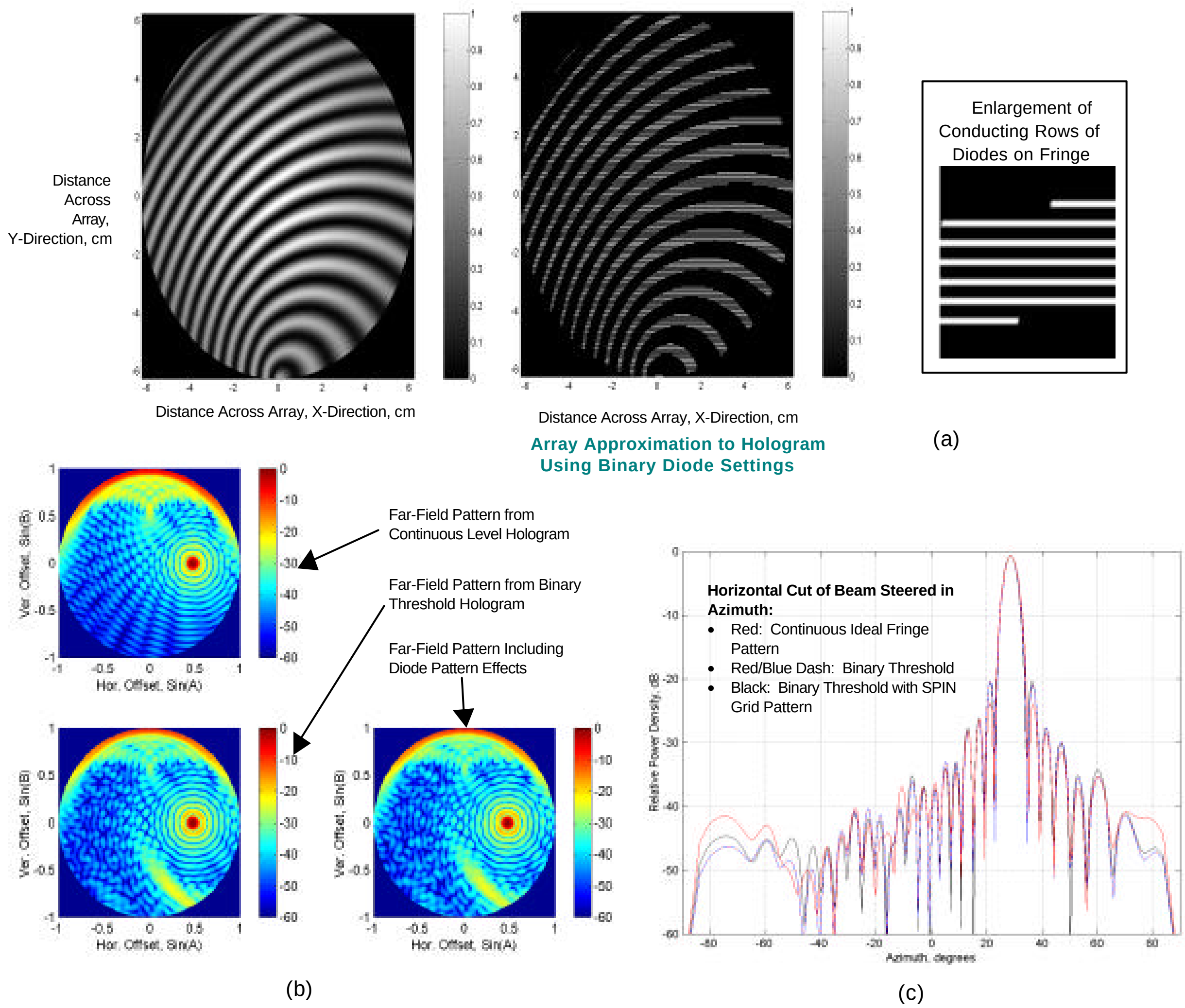


Fig. 6. (a) The continuos fringe pattern of the hologram and its discretization. (b) Effect of discretization and SPIN patterns on the far field. (c) Cartesian plot of the effects of discretization and SPIN devices patterns.

VI. Summary and Conclusions

Sarnoff has developed the technology to fabricate SPIN devices. These devices offer another practical alternative to MEMs for reconfigurable antenna apertures. Sarnoff has optimized their configuration to confine plasma domains at the surface. Plasma radiators have been fabricated and their radiation patterns were measured. More processing is still required to further improve the device carrier confinement and isolation.

Sarnoff has extensively analyzed the holographic antennas and their feed structures using HFSS for EM analysis and MATLAB for digital signal processing and holograms predictions.

Acknowledgement

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