

Ultra-fast Reconfigurable Intelligent Surfaces Based on Chalcogenide Alloys for U-Band Applications

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Abstract—This paper presents an energy efficient tuning mechanism for reconfigurable intelligent surfaces (RIS) utilizing chalcogenide materials such as GST (germanium antimony telluride) alloys. The presented approach offers an analog-type output phase reconfigurability providing seamless passive beam steering and eliminates the need for any soldered components or wiring. The heaters are monolithically integrated to provide actuation mechanism underneath the chalcogenide layer. This approach doesn't consume any static DC power consumption as the tunable element latches in a specified state. Full wave electromagnetic simulations demonstrate tuning over U-band. In addition, a comparison of the full-wave power distribution is presented to highlight the benefit of RIS.

I. INTRODUCTION

It is becoming important to design a new wireless architecture incorporating innovative technologies to address the highly demanding data rate requirements of future wireless networks while keeping the energy consumption low. Green and sustainable wireless networks are in demand.

The ideal candidate for the green or energy efficient communication approach is the recently emerging reconfigurable intelligent surface (RIS) technology [1], [2]. A RIS is composed of a two-dimensional array of low-cost and energy-efficient reconfigurable elements that can reflect impinging electromagnetic (EM) waves at a desired angle by providing an electronically controlled phase shift. The almost-passive beamforming can be used to achieve improved wireless coverage by smartly placing these almost unnoticeable surfaces on the objects such as building facades, billboards, windows, etc. in the outdoors and ceilings, furniture, walls in the indoors. Most of the current RIS elements reported in literature use a stack of metal and dielectric layer and the reconfigurability is achieved by using one or more PIN diodes or using MEMS. Such designs are limited to only 1-bit or 2-bit output phase states [3], [4].

This paper presents a novel idea for a RIS element using chalcogenide materials such as GST (germanium antimony telluride) alloys. The presented approach offers an analog-like output phase reconfigurability providing seamless passive beam steering and eliminates the need for any soldered elements. Apart from the clean monolithic integration, the major advantage of this technique is its zero static DC power consumption.

II. PROPOSED DESIGN

In the proposed unit-cell design shown in Fig. 1, the topmost layer is a uniform layer of a chalcogenide GST alloy. The second layer is a thermally conductive layer of a material

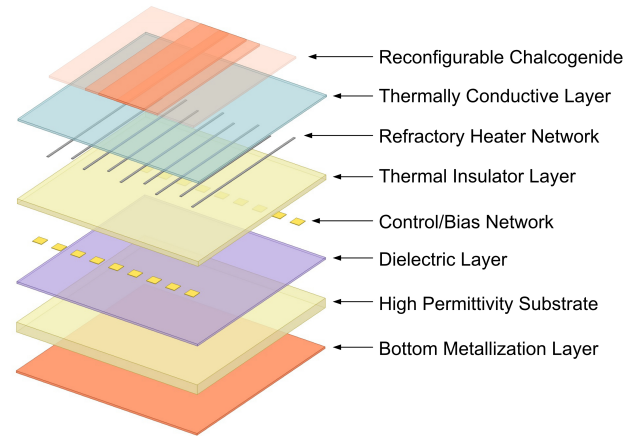


Fig. 1. A 3D view of the multi-layer structure of a proposed unit-cell design where reconfigurability is achieved by using chalcogenide material layer.

such as AlN (Alumina Nitride). The heater network is formed on third layer using refractory metal such as W (Tungsten) followed by a layer of thermally insulator material SiO₂ (Silicon dioxide). The thermally conductive layer on the top of heater network allows maximum heat to conduct to the GST alloy, while the thermally insulator material below the heater network prevents the heat flow downwards. The bias network for the heaters is designed on fifth layer using a standard metallization layer such as Cu (Copper) or Al (Aluminum), followed by a dielectric layer, which is coated on a high permittivity substrate such as Rogers RO or Al₂O₃ (Alumina Oxide). The bottom of the substrate is coated by a another thin metallization layer which acts as a ground for the RIS element.

III. WORKING PRINCIPLE OF THE PROPOSED METHOD

The operation principle is based on the many orders of magnitude resistance change that chalcogenide phase change GST alloys undergo when provided a specific heat treatment using a pulse [5]. Such materials can reversibly transition between a low resistance (metallic) state to a high resistance (dielectric) state. This transition occurs due to the change in crystal structure of the alloy, which changes from amorphous to crystalline. In order to control the state of the material from crystalline to amorphous, a matrix of heaters is placed under the chalcogenide material layer. The narrow width heaters can be individually actuated by an electronic pulse. In the absence of any actuation, the material is in its amorphous (high resistance) state and acts as an insulator. A limited area

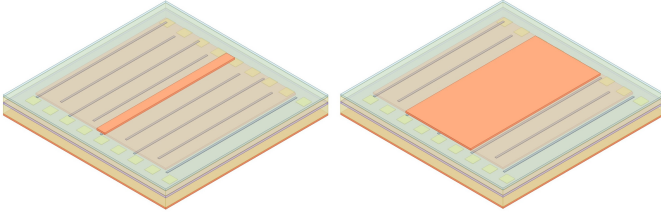


Fig. 2. The RIS unit-cell model where the top layer GST alloy is reconfigurable to highlight the change of conductive geometry of the cell.

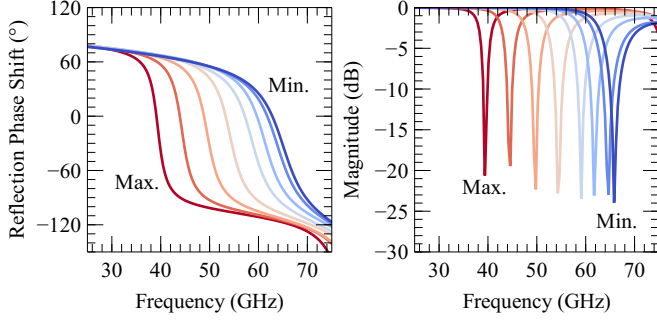


Fig. 3. Full wave response of the (left) reflected phase shift and (right) magnitude response with a change in the width of the GST patch demonstrating broadband response over *U*-band and covers up to 60% of the *V*-band.

of chalcogenide material is actuated by each heater and as more and more heaters are actuated; larger and larger area of the material will transition to the low resistance metal state. Hence, a dynamic change in the shape of the reflection surface can be achieved at a high speed, which will provide the reconfigurable operation.

An important point to emphasize here is that GST alloys need an electrical pulse only during the phase transition either from insulator to metal or vice versa. Once the material switched its state, it latches into that state and does not need any continuous power to stay in that state. This is an advantage as the overall power consumption of the RIS panel is largely reduced when operated for extended periods of time.

The heat provided by a heater is highly localized with no thermal crosstalk between the adjacent heaters, hence the conducting patterns can be generated on the top layer by actuating specific heaters. As shown in Fig. 2, the conducting metallic surface can be expanded in the width by controlling the 1D heater matrix. The proposed RIS allows generating conducting patches of any width, in the same manner as generating an image on a screen within a span of few nanoseconds. The exact switching time and the actuation pulse duration's depend on the ratio of the three elements in $G_xS_yT_z$ alloy used, where x , y , and z ratio can vary from 0 to 1.

IV. VALIDATION OF PHASE AND RESONANCE

Ansys HFSS is used for simulating the change in RF reflection characteristics of the proposed unit cell with the expansion/shrinkage of the conductive area of the GST alloy. Each heater can actuate an area of 0.1 mm; hence the simulations are performed with a step size of 0.1 mm in

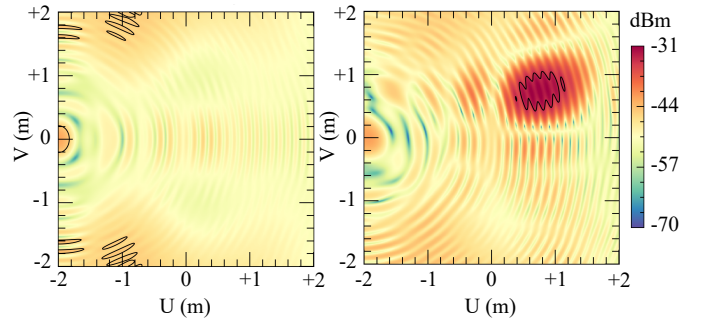


Fig. 4. Power received at $x = 2$ m, $y = 0$ m, and $z = 5$ m in 3D space, (left) with just the drywall, (right) RIS present on the drywall.

width. The phase shift offered to the reflected EM signal from the unit cell can also be tuned by changing the width of the conductive patch of GST alloy as displayed in the simulated performance in Fig. 3. The corresponding shift in the resonance in magnitude is also presented, demonstrating 27 GHz bandwidth over *U*-Band and spanning towards *V*-Band.

A RIS lattice is formed by a 2D array of the proposed unit-cells, each of which is capable of reflecting the EM signal with an electronically controllable phase shift. An 8x8 array is simulated using Dell R750 Servers. The size and shape of the conducting section of GST alloy is adjusted in real-time depending on the channel and coverage needs.

$$W = \int_S \text{Re}(\vec{P}) \cdot \vec{n} dS \quad (1)$$

where, S is the surface for power calculation and $\vec{n}$ is the normal vector to the surface, S . This calculation is used on scattered field data resulting from an incident source beam to evaluate reflection from a RIS at any point in 3D space.

A 2D plot of the total power received from the RIS is evaluated using Ansys HFSS as shown in Fig. 4. The net power flow through a surface is computed using Eq. 1. Fig. 4 shows an investigation window of size 2×2 m, with coordinates $x = 2$ m, $y = 0$ m, and $z = 5$ m in 3D space, where the Fig. 4 (left) shows the response without the surface and having just the standard drywall, while the Fig. 4 (right) shows the response with RIS present. A beam of -31 dBm is fairly distinguishable with dark boundary is representing 50% power.

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