

Fully Printed Flexible and Reconfigurable Antenna With Novel Phase Change VO₂ Ink Based Switch

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Abstract— Vanadium dioxide (VO₂) is identified as an attractive phase change material which can be used for switchable or reconfigurable RF components. At present, VO₂ is deposited by expensive and complex thin film micro-fabrication techniques. With the surge in low cost, additively manufactured or printed components, it will be beneficial to print phase change materials or switches as well. However, these kinds of functional inks are not available commercially. In this work, we present, for the first time VO₂ based ink that changes its conductive properties based on temperature. Precisely, it displays insulating properties at room temperature (resistance of ~1.2KΩ in the off-state), but becomes conductive when heated around 70°C (resistance of <10Ω in the on-state). Here, we demonstrate a fully printed thermally controlled reconfigurable antenna based on VO₂ ink and a custom silver-organo-complex (SOC) ink supported on flexible kapton substrate. In a planar inverted F antenna (PIFA) configuration, when the switch is in the OFF state, the antenna operates at 3.5 GHz band for 5G communications, and when it is in the ON state, it operates at 2.4 GHz band suitable for WiFi, Bluetooth or Zigbee applications. The antenna performance is assessed in different bending conditions where it achieved a maximum gain of ~2 dBi at 3.2GHz with concave bending position.

Keywords—Vanadium dioxide, inkjet-printing, antenna, phase change, broadband, bending test

I. INTRODUCTION

Reconfigurable or tunable components are increasingly in high demands due to their wide range application in multiband and functional wireless devices. In addition to the multiband requirement, flexibility and bending support is required in many cases. There are several tunable and switchable technologies have been explored such as p-i-n diodes, RF micro-electro-mechanical systems (RF-MEMS) based capacitive switches, ferrite and varactors based devices [1-3]. However, these technologies are relied on subtractive photolithographic process which not only provides a complex fabrication protocol but a lot of chemical wastage is obvious.

In contrast to subtractive process, inkjet printing or additive technology is extremely low cost, completely digital and highly suitable for rapid prototyping or large scale manufacturing. However, it required the development of functional inks, which can tune their electrical and optical properties with external stimuli such as temperature, light, applied field or voltage. Among them phase-change materials such as chalcogenides and vanadium oxide provide an interesting alternative which can tune its electrical properties

with temperature or incident light. Among them, vanadium dioxide (VO₂) has emerged as an attractive material which exhibits an interesting property of thermal tuning from metal to insulator transition (MIT) in abrupt and a reversible fashion [4]. This makes vanadium dioxide a promising material for high speed switching and reconfigurable devices. Recently, vanadium dioxide has been used to demonstrate various RF devices such as in switching, reconfigurable antenna, and MEMS actuators [5-6]. In all these fabrication process, vanadium dioxide is deposited by the pulsed laser deposition (PLD) technique in an ultra-high vacuum pressure (8×10^{-6} Torr) and high temperature (> 550 °C) environment. Thus, it makes the fabrication quite complex and expensive and it will be neat if the same fabrication can be done through printing.

In this work, we present a fully printed process utilizing a novel VO₂ nanoparticles based ink for demonstrating thermal switching and a custom silver-organo-complex (SOC) ink for inkjet-printing reconfigurable PIFA antenna supported on flexible substrate. The VO₂ ink, in this work, has been characterized for its dc performance and confirmed insulating properties at room temperature (resistance of ~1.2 KΩ in the OFF-state), and conductive properties when heated around 70°C (resistance of ~10Ω in the ON-state). The printed antenna operates at 3.5 GHz when the VO₂ switch is in OFF state, and when it is in ON state, it operates at 2.4 GHz. The antenna performance is also assessed with different bending condition such as in convex and concave bent configurations. The overall performance does not change much except a few MHz shift in both bending condition but match well with the frequency band of interest.

II. MATERIALS AND FABRICATION

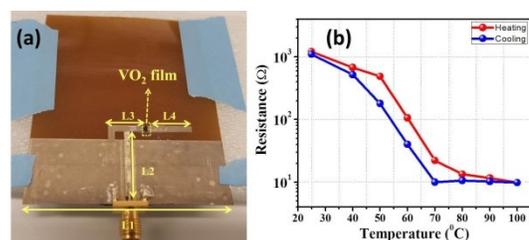


Fig. 1. (a) Fabricated prototype & (b) measured DC resistance of printed VO₂ film

VO₂ is prepared in the form of nanoparticles by a simple solution process. Typically, VO₂ material has many crystalline structure phases, however, the preferable phase is monoclinic VO₂ (M) which has the ability to show low temperature (at 68

$^{\circ}\text{C}$) phase transition [4]. To obtain the VO_2 (M) phase, as-prepared nanoparticles were optimized with annealing condition such as 200°C for 1h in vacuum. The prototype of the antenna was fabricated, as shown in Fig. 1 (a), utilizing a silver-organo-complex (SOC) ink with dimensions of (mm): $L_1=60$, $L_2=21$, $L_3=11.8$, $L_4=15.2$ with the gap between L_3 and L_4 is 0.2 mm. The VO_2 ink has been prepared by mixing the 33 wt% VO_2 nanoparticles in 66 vol % of 2-hydroxyethylcellulose, HEC solution (2 wt % in 50:50 ratio of water and ethanol). The SOC metallic ink is prepared according to report in [7]. In this particular case, a total of 8 layers of SOC ink is printed and cured using infrared (IR) heating for 5 min. The SMA is mounted to the coplanar waveguide line.

For the DC characterization, current-voltage (I-V) measurements have been performed to extract the resistance of the printed VO_2 film ($L=200\ \mu\text{m}$ and $W=2000\ \mu\text{m}$) in between the gap of antenna arm. I-V measurements have been performed using a Keysight B2912A precision source meter on a hot chuck probe station capable of temperature control from $5\text{-}200^{\circ}\text{C}$. At room temperature, the resistance is around $1.2\text{K}\Omega$, which almost shows an insulating behavior, as shown in Fig. 1(b). As the temperature is reached up to 70°C , the resistance reduces prominently with a value around 10Ω . When the temperature is reversed from high temperature to low temperature (cooling stage), the resistance recovers its initial value.

III. BENDING TEST ON ANTENNA WITH SWITCH

In order to assess the antenna performance with bending condition, the printed PIFA antenna is bent with 20 and 40 mm convex and concave configuration, as shown in Fig. 2. The S_{11} of the antenna with flat condition, as shown in Fig 2 (a&b) is less than -10 dB in the frequency band of 2.57-3.40 GHz when the switch is at "OFF" state, and in the frequency band of 1.65-2.60 GHz when at ON state. In case of concave bending, a maximum shift of 10 MHz is observed when the switch is at OFF state and 10-40 MHz in ON state. The wide impedance bandwidth of the antenna still retains the matching at the desired operating frequencies with different bending condition, as compared in Table I. The radiation patterns in the bent configurations are also measured for antenna in OFF state, as shown in Fig. 3. In case of the concave bending of 20 mm,

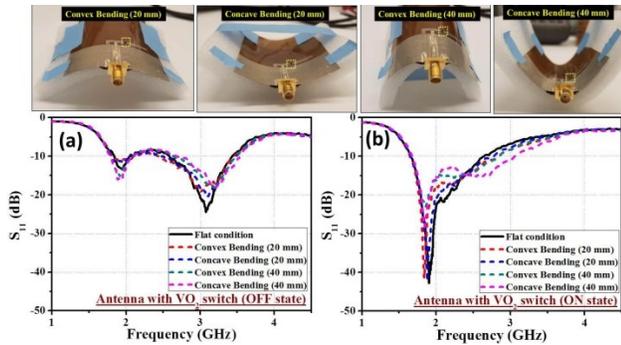


Fig. 2. The reflection coefficient of antenna with VO_2 switch ON/OFF at different bending condition

maximum gain of 2 dB is observed in the frequency band at 3.2 GHz due to slight increase in the directivity when antenna is bent. However, the gain is further reduced with convex and 40 mm concave bending.

TABLE I. ANTENNA BANDWIDTH COMPARISON WITH DIFFERENT BENDING CONDITION

	Flat	Convex (20 mm)	Concave (20 mm)	Convex (40 mm)	Concave (40 mm)
Switch OFF	2.57-3.40	2.45-3.44	2.55-3.50	2.60-3.48	2.60-3.50
Switch ON	1.65-2.60	1.65-2.80	1.65-2.70	1.66-2.80	1.67-3.00

IV. CONCLUSION

In this report, we presented a novel VO_2 nanoparticles based phase change ink which can be thermally tuned for its electrical properties. To demonstrate the phase change behavior of printed VO_2 film, reconfigurable PIFA antenna is fabricated. The antenna is able to switch between two bands with printed VO_2 film in ON/OFF state. The switching performance confirmed that printed VO_2 can be very useful for implementation of several tunable and reconfigurable microwave designs.

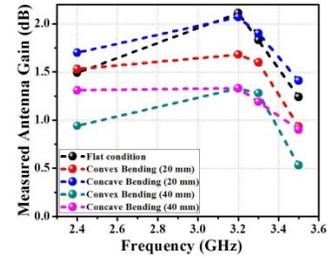


Fig. 3. The measured antenna gain with switch in OFF state

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