Package-Platformed Linear/Circular Polarization Reconfigurable Antenna Using an Integrated Silicon RF MEMS Switch

Ik-Jae Hyeon, Tony J. Jung, Sungjoon Lim, and Chang-Wook Baek

This letter presents a K-band polarization reconfigurable antenna integrated with a silicon radio frequency MEMS switch into the form of a compact package. The proposed antenna can change its state from linear polarization (LP) to circular polarization (CP) by actuating the MEMS switch, which controls the configuration of the coupling ring slot. Low-loss quartz is used for a radiating patch substrate and at the same time for a packaging lid by stacking it onto the MEMS substrate, which can increase the system integrity. The fabricated antenna shows broadband impedance matching and exhibits high axial ratios better than 15 dB in the LP and small axial ratios in the CP, with a minimum value of 0.002 dB at 20.8 GHz in the K-band.

Keywords: Reconfigurable antenna, polarization, silicon RF MEMS switch, packaging, silicon-on-quartz.

I. Introduction

With the remarkable growth of wireless communication systems, there has been an increasing need for multifunctional antennas that can cover various communication environments [1]. In recent research, significant attention has been paid to reconfigurable antennas, that is, antennas that can alter their radiating topology within the same physical dimension, due to their selectivity of frequency, radiation or polarization, and compact size [2]. Reconfigurable antennas can be applied to a variety of radio frequency (RF) communication systems; for example, frequency reconfigurable antennas for multiband mobile devices and polarization reconfigurable antennas for satellite communication systems, RF identification modulators, or adaptive multi-input multi-output systems.

Reconfigurable antennas are usually realized by changing the configuration of the antenna using tunable devices, such as PIN diodes, varactor diodes, or field effect transistors. The semiconductor-based switching element, however, is not a good choice for higher frequency applications such as millimeter-wave devices because it suffers from higher losses as the frequency increases. For such frequency regions, RF MEMS switches could be ideal alternatives giving very good RF performances. They offer very low insertion losses, high linearity, and low power consumption. Also, they can be easily integrated into other microwave components with simple bias circuits [3].

Reconfigurable antennas, which can reconfigure the resonant frequency, radiation patterns, or polarization states, have been previously reported by using MEMS switches or varactors [4]-[7]. Most of these antennas, however, are simply integrated with RF MEMS without considering MEMS packaging, which is a crucial factor for reliability of the device in practical applications. Sometimes, fully packaged RF MEMS switches are connected to the antenna via wire-bonding [6], [7], but this increases fabrication complexity and cost and degrades antenna performance due to the parasitic effects from the bondwires.

In this letter, a *K*-band linear polarization (LP)/circular polarization (CP) reconfigurable antenna, integrated with a robust single crystal silicon (SCS) RF MEMS switch, is presented. For efficient polarization switching capability, a ring

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slot antenna [8], [9] is employed. The proposed antenna can simply switch its polarization state from LP to CP by connecting a stub to a ring slot coupled to a radiation patch with electrostatic actuation of the RF MEMS contact switch. The MEMS switch is efficiently integrated with the antenna into the form of a vertically-stacked compact package using the silicon-on-quartz (SoQ)/bisbenzocyclobutene (BCB) platform previously developed by our group [10]. Details of the antenna design, fabrication process, and the measured antenna performances will be described.

II. Antenna Structure and Operating Principles

The proposed LP/CP reconfigurable antenna structure is shown in Fig. 1. The antenna is composed of two parts. A ring slot for aperture coupling and a stub for exciting circular polarization are formed with finite ground coplanar waveguide feedlines and an impedance transformer on the bottom glass substrate. An SCS RF MEMS contact switch is located on the disconnected span between the center circular conductor and the stub.

On the other hand, a radiating patch is formed on one side of the top fused quartz substrate with patterned rectangular silicon/BCB rims on the other side. The top substrate, in combination with air below it, plays a role of a dielectric material for the radiating patch, and thus fused quartz is chosen as a substrate material thanks to its low-loss properties at

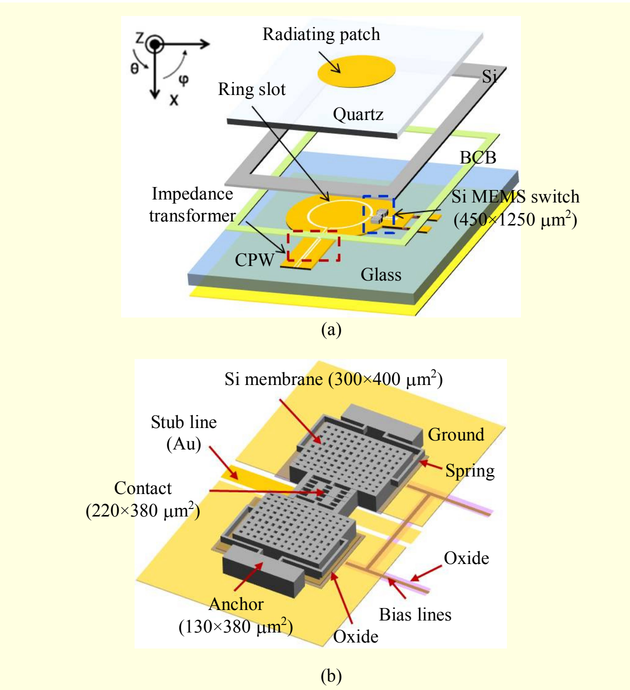

Fig. 1. (a) Schematic view of proposed LP/CP reconfigurable antenna and (b) enlarged view of MEMS switch.

millimeter-wave frequencies. Besides, it is also used for a capping substrate to encapsulate the RF MEMS switch. The top substrate is vertically stacked onto the bottom glass substrate and bonded with it using the BCB rim as an intermediate adhesive layer. BCB, a well-known RF packaging material, is used as a bonding material because of its excellent microwave properties and good resistance to gas and moisture [10]. Silicon rim is also used with BCB to obtain enough space for the RF MEMS switch to be packaged as well as to adjust the distance between the bottom and top substrates for optimal electromagnetic coupling.

Operating principles of the proposed antenna are simply described as follows. The CP radiation is generated by exciting two orthogonal modes when the MEMS switch goes to the ON state. The 90 degree phase difference is achieved by adjusting the radius of the ring slot and the length of the stub.

Since the stub length is critical to generate the CP radiation, the MEMS switch is placed to control the stub length. When the switch is in the OFF state, the LP radiation is achieved by disconnecting the stub from the ring slot.

III. Antenna Fabrication Process

The overall fabrication process of the proposed antenna is illustrated in Fig. 2. Fabrication of the bottom substrate is basically based on the silicon-on-glass process previously developed by our group [11] but partially modified here for the proposed antenna. The process starts with patterning of Cr (10 nm)/Ni (200 nm) bias lines on a 4-inch glass wafer using a lift-off process and is followed by patterning a 200-nm-thick oxide layer on the bias lines for electrical isolation (Fig. 2(a)). A 3-μm-thick gold layer is electroplated to form signal lines with the ring slot and stub, and then another 200-nm-thick oxide layer is patterned to protect electrical shorting of the silicon switch membrane (Fig. 2(b)). The process for the silicon MEMS switch is almost the same as in [11], except for the two-step deep reactive ion etching (DRIE) process to make mechanical springs thinner than silicon actuating membranes, which can reduce the actuation voltage of the MEMS switch (Figs. 2(c) and 2(d)). The two substrates are anodically bonded and a 500-nm-thick gold layer is patterned on the backside of the glass wafer as a reflector (Fig. 2(e)). The switch membranes and springs are defined by DRIE of silicon (Fig. 2(f)).

Fabrication of the top substrate is based on the SoQ/BCB platform developed in our group [10]. After bonding 500-μm-thick fused quartz and silicon wafers, they are thinned down to 300 μm for quartz and 85 μm for silicon, respectively, and a 500-nm-thick gold radiation patch is patterned on the quartz (Fig. 2(g)). The backside silicon is etched by DRIE to make a

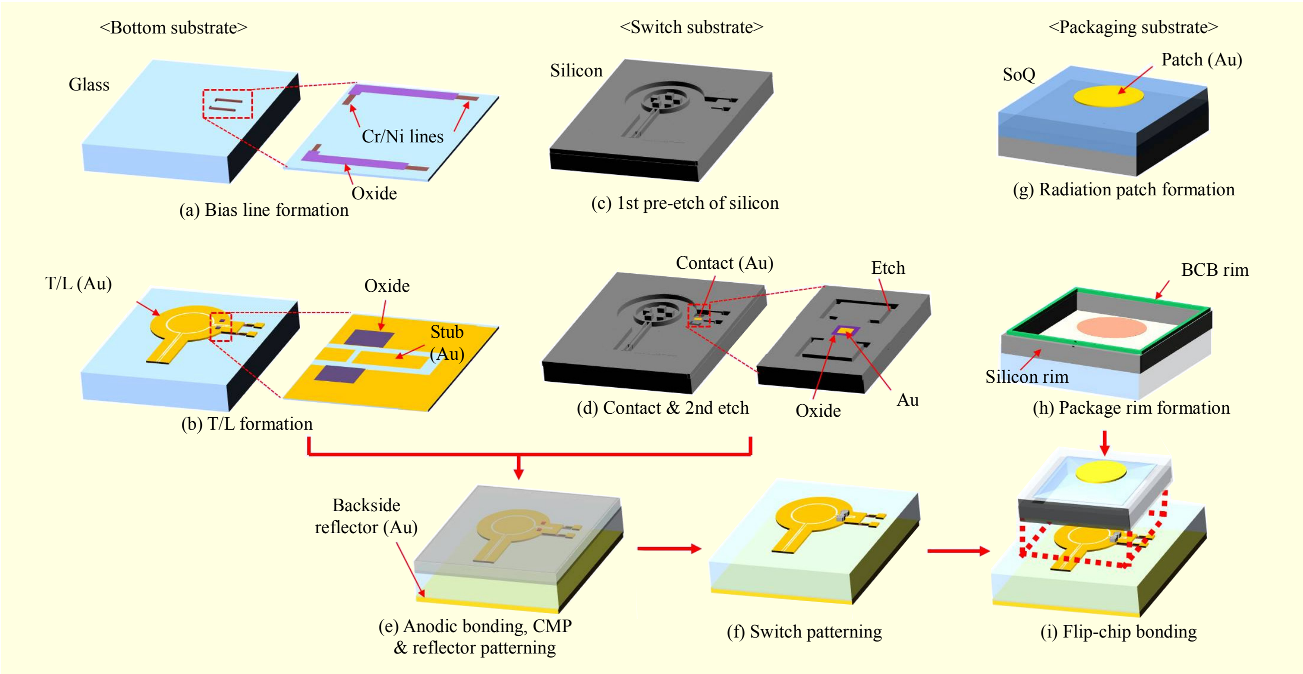

Fig. 2. Fabrication process flow of antenna.

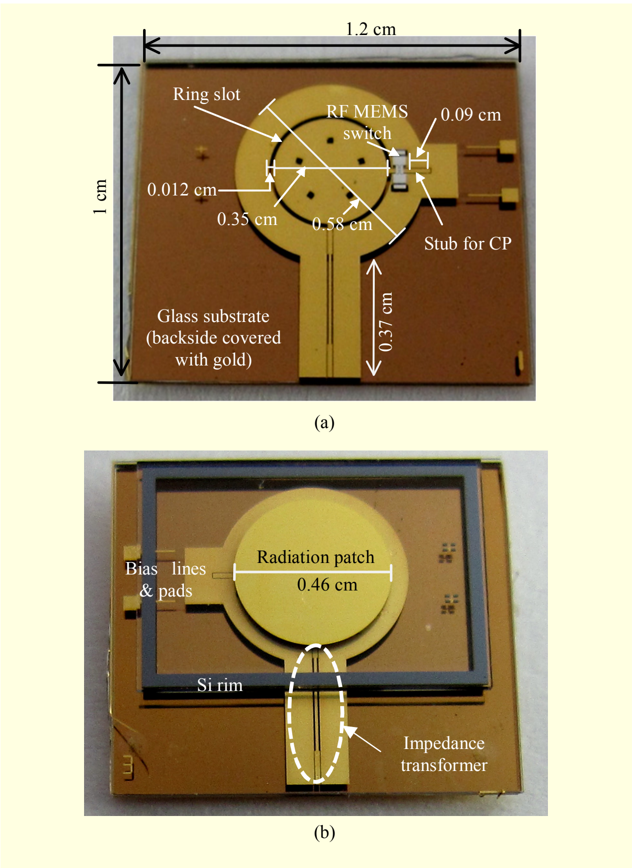

Fig. 3. Photographs of fabricated antenna: (a) bottom RF MEMS glass substrate and (b) completed antenna after packaging with the top quartz substrate.

space for MEMS packaging, followed by patterning an 18-μm-thick BCB adhesive polymer layer (Fig. 2(h)).

As a final step, the top and bottom substrates are diced and flip-chip bonded using BCB as an adhesive layer to construct the packaged antenna (Fig. 2(i)). BCB is thermally cured at a final temperature of 210°C for 20 minutes under the applied force of 30 N, resulting in the final thickness of 15 μm. Photographs of the fabricated antenna are shown in Fig. 3. The total device size after assembling is 1.2 cm×1.0 cm.

IV. Measurement Results

The pull-in voltage of the fabricated RF MEMS switch was measured to be about 9.5 V, which is slightly higher than the designed value of 7.4 V. The higher actuation voltage is caused by the changes in the actuation gap and spring thickness, which are due to the fabrication errors. The switching speed of the switch was measured to be 128 μs. The reflection coefficients of the fabricated antenna were measured for both LP (MEMS switch OFF) and CP (MEMS switch ON) states using an HP8510C vector network analyzer and compared with the Ansoft high frequency structure simulator simulation results, as shown in Fig. 4. The antenna shows good impedance matching with broadband frequency range of *K*-band. The measured 10-dB bandwidths were from 17.3 GHz to 22.0 GHz (23.8%) for the LP state and 16.8 GHz to 22.6 GHz (29%) for the CP state.

The axial ratio, which is defined as a ratio of a magnitude

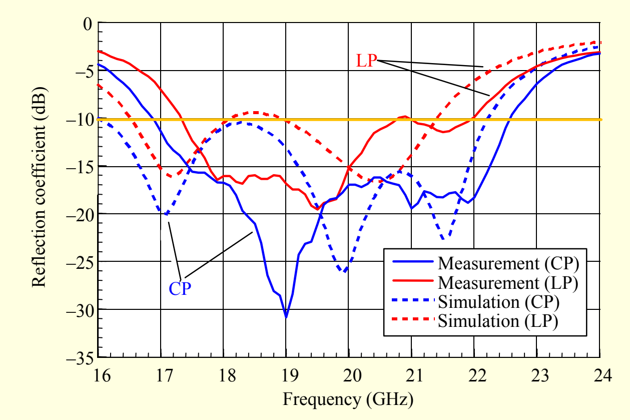

Fig. 4. Simulated and measured reflection coefficient of fabricated antenna.

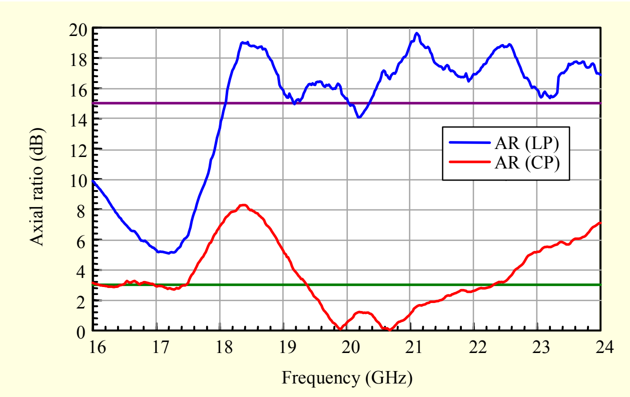

Fig. 5. Measured axial ratios of fabricated antenna at broadside.

between the major and minor axis field vectors, is an important parameter to evaluate the quality of each polarization state. Theoretically, a large axial ratio for the LP state (typically >15 dB) and a small axial ratio for the CP state (typically <3 dB) are desirable. The axial ratios of the fabricated antenna for both states were measured as shown in Fig. 5 by monitoring the power level of a receiving horn antenna located at the broadside ($\theta = 0°$) and about 1 m apart from the antenna. The axial ratio for the LP state was better than 15 dB in the measured frequencies above 18 GHz, with a maximum value of 19.6 dB at 21.1 GHz. The axial ratio for the CP state was kept distinguishably lower than that of the LP state, especially below 3 dB from 19.4 GHz to 22.3 GHz with a minimum value of 0.002 dB at 20.8 GHz. These results imply that both LP and CP states are successfully excited. The maximum total gains of the antenna were measured to be 2.7 dBi at 21.0 GHz for the LP state and 4.1 dBi at 21.7 GHz for the CP state.

V. Conclusion

In this letter, a novel package-platformed *K*-band LP/CP reconfigurable antenna operated by the integrated silicon RF MEMS switch has been proposed and successfully demonstrated. The antenna shows wideband performances and good axial ratios for the LP and CP states by using ring slot and stub configuration with the help of excellent RF performances of the MEMS switch. The proposed antenna offers an efficient and compact platform for MEMS-based reconfigurable antenna and is expected to be used in adaptive smart antenna systems.

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