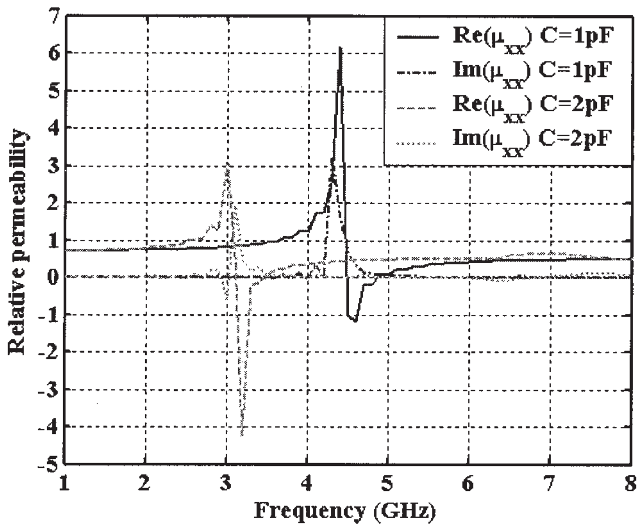

Figure 4 Demonstration of the tunability of the meta-cube

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A NEW PLANAR-TYPE DIELECTRIC RESONATOR USING LTCC TECHNOLOGY FOR mm-WAVE BAND APPLICATIONS

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ABSTRACT: *A new planar-type dielectric resonator (PDR) with a high unloaded* Q *has been developed using LTCC Technology. The PDR consists of two different dielectric constant materials, high dielectric LTCC cavity (ε_r = 36) acting as a resonator and low dielectric LTCC layer (ε_r = 5.2) surrounding the cavity. Also, the layer has staggered air holes on the top and bottom of the resonator instead of the air cavity of the original PDR, a hollow patch center ground plane at the middle, and shielded cavity metals. The newly realized PDR structure shows a high unloaded* Q *of about 6212 at 37.3 GHz and the measured results are in good agreement with the simulated ones. The PDR can be easily integrated into a planar circuit and can be applicable to mm-wave band systems.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 44: 533–536, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20688

Key words: *DR; PDR; staggered air hole; LTCC*

1. INTRODUCTION

A high unloaded Q (Q_u) resonator is essential for low-phase noise oscillators and high Q filters [1]. In mm-wave-band, dielectric resonators (DR) are widely used to get a high unloaded Q. The requirements of the DR are high unloaded Q, small size, low insertion loss, high temperature stability, productivity, and low cost. Recently, a planar-type dielectric resonator (PDR) using a high dielectric substrate, which can deliver a high unloaded Q and be easily integrated with multilayer MICs, has been reported [2–4]. For a PDR operating in the TE_{010} mode, most of the electromagnetic field energy is confined inside the DR and decreased exponentially outside the DR. Those PDRs have been reported to have a high unloaded Q of about 1610. However, the unloaded Q is rather low compared to the dielectric resonator because a strong electromagnetic field is formed at the edge of the ground plane, where a significant metal loss is generated and the unloaded Q of the PDR is degraded. Among substrate technologies, low-temperature co-fired ceramic (LTCC) technology is attracting microwave and mm-wave engineers' attention due to the 3D integration capability for size reduction and low cost, and the small-dielectric-loss tangent [5, 6].

This paper proposes a new PDR based on LTCC technology with a high-dielectric resonator embedded in a low-dielectric material in order to meet most of the above requirements. Our LTCC PDR has a disk-shaped high-dielectric LTCC cavity and one hollow-patch ground plane located at the center of a low-dielectric LTCC layer with staggered air holes at the top and bottom of the resonator. The PDR has a significantly improved unloaded Q and reduced size, as compared to other PDRs. Also, it has a merit of manufacturability because it does not need any separate air gap or

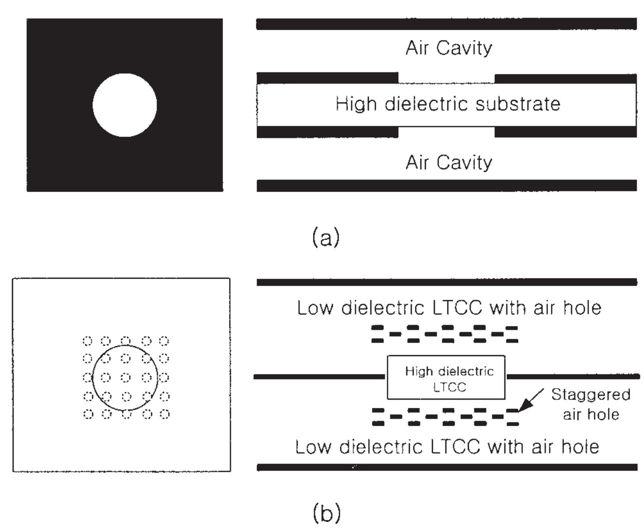

Figure 1 Configurations of PDRs (a) PDR with double ground (b) proposed LTCC PDR with staggered air hole.

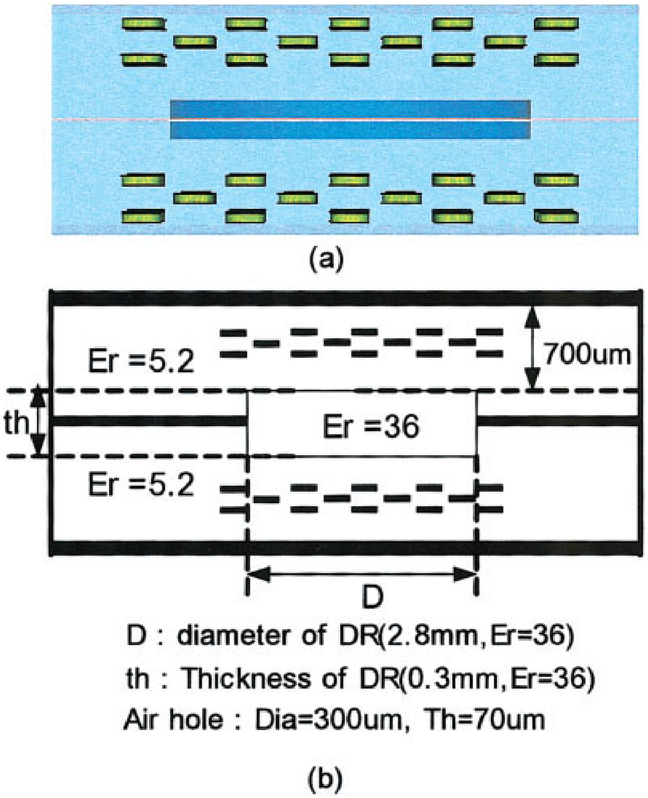

Figure 2 PDR configuration used for analysis. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

metal cavity, but is fully filled with a dielectric material. Moreover, it is easily integrated into planar circuits.

2. PLANAR DIELECTRIC RESONATOR

2.1. Configuration

Configurations of PDRs are shown in Figure 1. The PDR proposed in [2] is shown in Figure 1(a). It consists of a high-dielectric substrate, ground planes on both side of the substrate with a circular hollow patch of the same diameter, and air gaps between the substrate and the upper and lower metal plates. The dielectric part in the circular hollow patch acts as a resonator and the outer-ground metals form a cutoff region against the TE_{010} mode. Our proposed LTCC PDR is shown in Figure 1(b). It consists of a high-dielectric LTCC ($\varepsilon_r = 36$) layer acting as a resonator, a low-dielectric LTCC layer surrounding the resonator with staggered air holes between the top and bottom of the resonator ($\varepsilon_r = 5.2$), and one ground plane with a circular hollow patch of the same diameter as the resonator at the center of the low-dielectric LTCC layer ($\varepsilon_r = 5.2$) [4]. In the PDR, the outer cavity and inner ground plane act as a partially loaded waveguide and create a cutoff region against the TE_{010} mode. Thus, there is a tightly confined electromagnetic field inside the hollow patch. The PDR structure with one center inner ground and staggered air holes in the low-dielectric layer provides higher unloaded Q than other PDRs due to the reduced electromagnetic field at the edge of the field-confining metals.

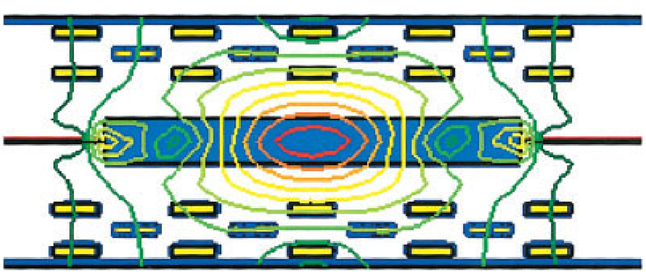

Figure 3 Contour line of magnetic field energy within PDR at 35.7 GHz. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

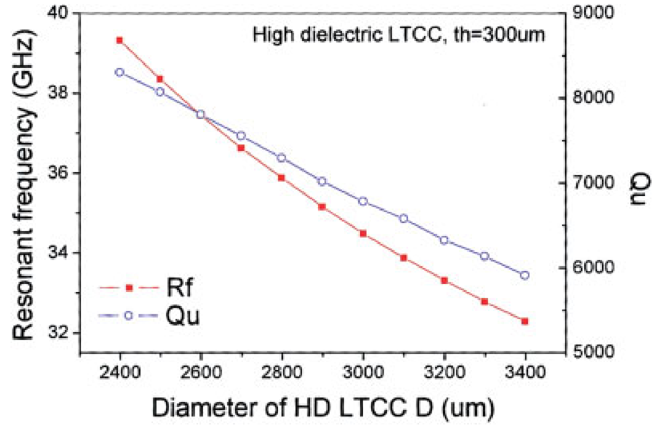

Figure 4 Relationship between the diameter of the high-dielectric LTCC and the resonant frequency and unloaded Q. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

2.2. EM Field Energy Distribution

In order to verify the performance of our proposed LTCC PDR, the electromagnetic-field energy distribution in the structure is calculated using an eigen-mode simulator (CST Microwave Studio). Figure 2 shows the PDR configuration used for the analysis. The magnetic-field energy distribution in the PDR is shown in Figure 3. The field distribution is similar to that of $TE_{01\delta}$ dielectric resonator. However, outside the resonator, it has a very strong cutoff region compared to the $TE_{01\delta}$ dielectric resonator. This factor signifies that most of the electric- and magnetic-field energy is concentrated in the dielectric resonator. Therefore, we can claim that the new PDR with one center inner ground and staggered air

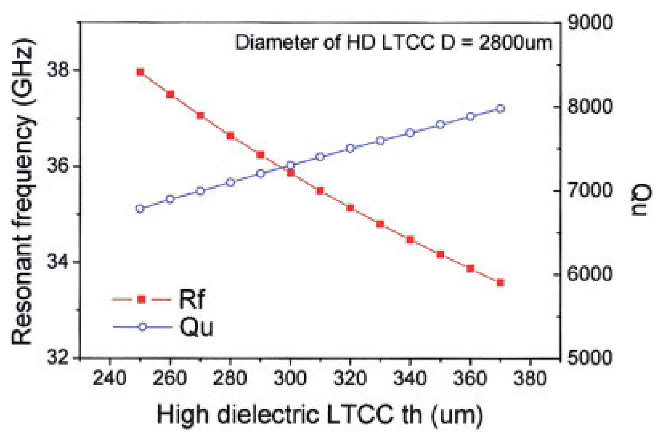

Figure 5 Relationship between the thickness of the high-dielectric LTCC and the resonant frequency and unloaded Q. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE 1 Effect of the Center Inner Ground Plane Location on the Resonant Frequency and Unloaded *Q*

Variation of the Center Ground and Via Hole *Q*	Resonant Frequency [GHz]	Unloaded *Q*
0 (center)	35.65	7500
10 μm	35.65	7491
20 μm	35.39	6795
50 μm	35.55	6662

holes in the low-dielectric LTCC layer supports the TE_{010} mode and has much higher unloaded *Q* than other PDRs.

3. PLANAR DIELECTRIC RESONATOR ANALYSIS

Resonant frequencies and unloaded *Q* are calculated for the model shown in Figure 2 using CST Microwave Studio. For the simulation, the dielectric constant of the high-dielectric LTCC (the dielectric resonator) is 36 and that of the low-dielectric LTCC (the cavity) is 5.2 with thickness of 700 μm, and the whole PDR size is 10 × 10 × 1.7 mm. The other parameters are variable.

3.1. Resonant Frequency

Figure 4 shows the relationship between the resonant frequency and unloaded *Q* versus the diameter of the high-dielectric LTCC with 300-μm thickness. Figure 5 shows the relationship between the resonant frequency and unloaded *Q* versus the thickness of the high-dielectric LTCC with 2800-μm diameter. As shown in Figures 4 and 5, the resonant frequency of the resonator becomes higher as the diameter and thickness of the high-dielectric LTCC is reduced, but the unloaded *Q* increases as the thickness of the high-dielectric LTCC is increased and/or the diameter is reduced. When the diameter is 2800 μm and the thickness is 300 μm, the LTCC PDR has approximately 35.7-GHz resonant frequency.

3.2. Unloaded Quality Factor

As shown in Figure 5, the LTCC PDR has very high unloaded *Q* of about 7500 at 36-GHz resonant frequency. It clearly shows that the PDR structure with a center inner ground and staggered air holes in the low-dielectric layer provides higher unloaded *Q* than a one- or two-sided ground structure because the electromagnetic-field profile is tightly confined vertically. Also, we have analyzed the misplacement effect of the center inner ground on unloaded *Q* using the simulator and the results are summarized in Table 1. Figure 6 shows the contour line of magnetic-field energy within the PDR when the center inner ground is up 50 μm from the middle point. It shows that the unloaded *Q* depends on the variation of the ground-plane location. Therefore, to obtain high unloaded *Q*, it should be located near the middle of the structure.

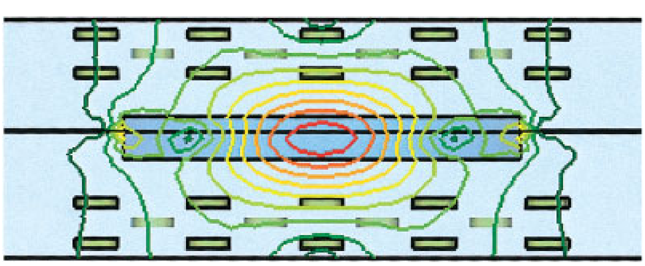

Figure 6 Contour line of the magnetic-field energy within the PDR with the center inner ground up to a 50-μm variation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

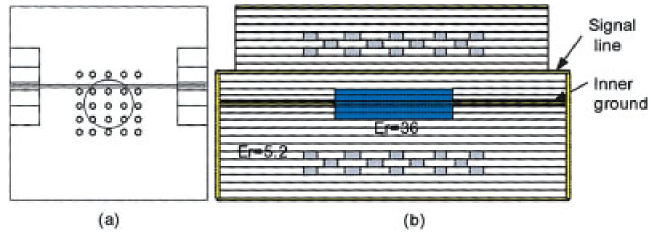

Figure 7 LTCC PDR structure. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

4. FABRICATION OF LTCC PDR AND TEST RESULTS

A 36-GHz LTCC PDR is fabricated using the 3D multilayered LTCC technology of PILKOR Ltd., Korea. It is laminated to form the 1.7-mm co-fired structure by using a stack of several layer tapes. The dimension of the PDR is adjusted in advance in order to obtain the designed dimensions after firing. The shrinkage is compensated at the green stage of making a co-fired PDT structure. The fabricated LTCC PDR consists of 27 green tapes, including the high-dielectric LTCC layer ($\varepsilon_r = 36$) and low-dielectric LTCC layer with staggered air holes ($\varepsilon_r = 5.2$) and four metal layers. The 100-μm width microstrip-line, made via the screen-printing LTCC process, is used for coupling to the dielectric resonator and to carry the signal. The conductor traces and ground plane are screen-printed on a separate stack of tape structures and then laminated together before co-firing. The signal line is located 200-μm above the high-dielectric LTCC layer, as shown in Figure 7.

The photograph of the fabricated LTCC PDR and test results are shown in Figures 8 and 9. The LTCC PDR is tested using an HP 8517B *S*-parameter test and on-wafer probe (50A-GSG-250-DP). The measured resonant frequency is 37.3 GHz and measured unloaded *Q* is about 6212.5. The errors between the simulation and test results are less than 5% and 20%, respectively, and we speculate that the errors are mainly due to the shrinkage and variation of the dielectric constant after co-firing and the simulation error for in/out port losses.

5. CONCLUSION

A new PDR based on the LTCC process for mm-wave band application has been proposed. The new PDR has a high-dielectric

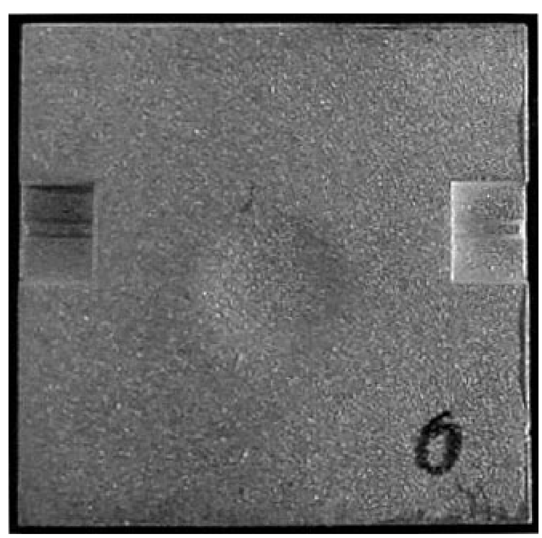

Figure 8 Photograph of fabricated LTCC PDR

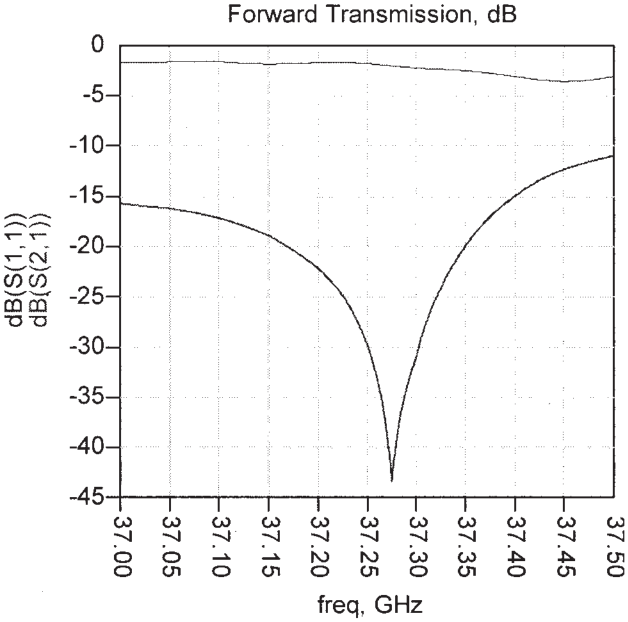

Figure 9 Test results of the fabricated LTCC PDR

disk-shaped resonator embedded in a low-dielectric material. One hollow-patch ground plane located at the center of the low-dielectric LTCC layer with staggered air holes at the top and bottom of the resonator supports the $TE_{01\delta}$ mode. The PDR has a significantly improved unloaded Q and reduced size. The measured resonant frequency of the realized PDR is 37.3 GHz and the unload quality factor is 6212.5, which are in good agreement with the simulated ones. Moreover, a new LTCC PDR can be easily integrated into a planar circuit and can be applicable to mm-wave band circuits and systems.

ACKNOWLEDGMENTS

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PARALLEL-COUPLED PHASE-MATCHED MULTIRING OPTICAL FILTERS

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ABSTRACT: *A periodic bandpass filter that is based on the phase-matching principle and consists of several parallel-coupled microrings is presented. The rings are identical in size; the coupling coefficients are chosen to provide maximally flat or equal ripple passband. Simulated filter characteristics exhibit steep roll-off and large stopband rejection. Expressions are given to estimate the passband insertion loss and the stopband rejection level. The effects of loss and fabrication tolerances is examined.* © 2005 Wiley Periodicals, Inc. Microwave Opt Technol Lett 44: 536–540, 2005; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.20689

Key words: *microring resonator; optical channel filter; add/drop filter*

1. INTRODUCTION

This paper describes the design and properties of periodic, multiring band-pass filters featuring a wide and flat passband, steep roll-off, and large stopband rejection. The filters are based on the phase-matching principle and use a novel cascaded architecture. The ring resonators have identical perimeters and the coupling-coefficient distribution provides either a maximally flat or Butterworth (B) or an equal ripple or Chebyshev (C) passband characteristic.

The parallel-coupled microring resonator filter, shown in Figure 1, has received considerable attention in the literature recently [1–7]. Its major application is channel separation and combined communication. Since there are usually a large number of closely packed channels in a group, the filter should exhibit steep skirts, wide free-spectral range (FSR), and large stop-band rejection. In [7], we proposed a simple parallel-coupled ring resonator add/drop filter consisting of only two rings, which was characterized by large and constant rejection in the stopband and an FSR adjusted by the perimeter of the resonators. The constant level of rejection in the stopband was the result of the phase-match between the signals dropped by the first and the second ring (not necessarily circular). More specifically, by selecting the distance between the couplers to be an odd number times a one-quarter guide wavelength ensured that the FSR of the resonators and the frequency separation corresponding to the delay between the two transmission paths was the same. The level of rejection was adjusted by a single parameter, namely, the coupling coefficient of the four

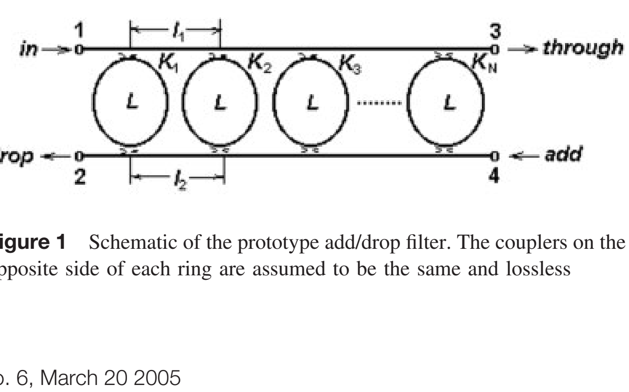

Figure 1 Schematic of the prototype add/drop filter. The couplers on the opposite side of each ring are assumed to be the same and lossless