Abstract—In this paper, a dual-resonance bandpass THz filter using a modified four-split CELC (MFC) metal-dielectric-metal structure with improved transmission performance is presented. The experimental results on THz time-domain spectroscopy (TDS) are in good agreement with simulations. Results show that the bandpass filter resonated at 0.315THz with substantial improvements in the low losses, steep skirts, high out-of-band rejection and slight in-band fluctuations.

I. INTRODUCTION

In the past decades, THz filters used metal mesh, resonant grid, split ring resonator and complementary electric-LC (CELC) structure as resonators[1-3]. Nevertheless, the CELC offers reasonable advantages in construction of high performance THz bandpass filter (BPF)[4-5], problems such as insertion losses, pass band fluctuations, unwanted resonances and substrate reduction still occur. Although cascade connection of bilayer FSSs with electrically thick substrates improved the THz filtering characteristics[6-7], the elaborate design is pre-requisite to avoid unwanted filtering characteristics and mechanical risks.

In summation, the MFC structure is proposed to provide a appropriate solution. Z-cut single crystal quartz is used as the substrate for its hardness and low loss in THz waveband. However, the substrate will be very fragile, because its thickness must be reduced to suit the higher resonant frequency. To enhance the electromagnetic coupling efficiency of the cascaded FSS resonators the MFC increase by the reduction of the surrounding metal loading ends are enhanced. Thus, in the vicinity of the central aperture the electric field is resonantly enhanced. The resonant frequencies of the MFC by the reduction of the surrounding metal inductance[10]. The electromagnetic coupling between bi-layer of the MFC is enhanced for the increment of the dielectric gap area.

The dimensions are $r_1=112 \mu m$, $w=77 \mu m$, $r_2=r_1-w=35 \mu m$, $r_3=60 \mu m$, $a=350 \mu m$ and the substrate thickness $d=155 \mu m$.

Fig.1. (a) Unit cell of FC. (b) Unit cell of MFC. (c) Bilayer structure

Fig. 2 shows the surface current density and the electric field distributions of the metal-dielectric interface plane for both the FC and the MFC metamaterials at 0.28 THz and 0.315 THz, respectively. The surface currents with two counter-circulating elliptical loops (the green arrows) in both the FC and MFC unit show only purely electric response. The difference is that the surface current flow distance of the MFC is shortened and the surface current couplings on the four loading ends are enhanced. Thus, in the vicinity of the central aperture the electric field is resonantly enhanced. The resonant frequencies of the MFC increases by the reduction of the surrounding metal inductance[10]. The electromagnetic coupling between bi-layer of the MFC is enhanced for the increment of the dielectric gap area.

II. RESULTS

A unit cell model of the metamaterial filter was constructed using periodic boundary conditions and Floquet ports in HFSS. The comparative analysis of resonant characteristic between FC and MFC is obtained. Fig. 3 (a) shows the simulated transmittance for the MFC and the FC using a maximized $w=52 \mu m$ with the other parameters fixed, represented as FC-1, all dimensions include the quartz thickness being linearly scaled by a factor of 1.14, represented as FC-2 and FC-3 is the original dimensions. Obviously, the MFC is superior in terms of in-band insertion loss and bandwidth to the FC.

The relative 3 dB fundamental bandwidths of the FC-1, FC-2 and MFC are 10%, 8.7% and 10.5%, centered at 0.314 THz, 0.315THz and 0.315THz, respectively. The fundamental in-band average insertion losses of the FC-1, the FC-2 and the MFC are 1.90 dB, 2.34 dB and 1.79 dB, respectively. With the degeneration of the filtering characteristics, the 136 \mu m thickness of the FC-2 can also lead to machining risks. As the strip width $w$ was maximized, the pass band of the FC-1 cannot be shifted to a higher region without reducing the substrate thickness or modulating the other dimensions. However, the resonant frequency and the bandwidth of the MFC clearly increase with increments in $r_3$, individually, as shown in Fig. 3 (b).

The MFC BPF was manufactured using standard micro-fabrication techniques. The TPS Spectra 3000 from TeraView was applied to

Fig.2. Simulation results of induced surface current and electric field distributions for (a) and (c) the FC, (b) and (d) the MFC

Fig.3. Simulated transmission of (a) FC and MFC. (b) MFC with different central radii

The MFC BPF was manufactured using standard micro-fabrication techniques. The TPS Spectra 3000 from TeraView was applied to
characterize the transmission spectra of the BPF. Fig. 4 with inset of the sample microscope picture shows that the measured transmittance spectra are in good agreement with the results of the simulations. There is no obvious spurious resonance caused by the etalon between the two bands, and the out-of-band rejection is acceptable.

The results show that the fundamental pass-band is centered at 0.315 THz, the average insertion loss is less than 2 dB, the fundamental in-band fluctuation is less than 0.8 dB, the second pass-band is centered at 0.48 THz, and the out-of-band rejection is approximately 50 dB around the first band.

III. SUMMARY

In conclusion, we have designed, fabricated and performed measurement on a dual-band THz bandpass filter. The enhancement of the filtering performances based on modified complementary metamaterial structures was obtained. The MFC BPF has the advantages of solidly-built at low cost, low loss, steepness of skirts, out-of-band rejection and in-band fluctuation.

REFERENCES