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Abstract – This paper gives an overview on recent achievements in micromachined technology for millimeter and submillimeter-wave applications, from 130 to 750 GHz. The micromachined components presented include the first ever submillimeter-wave MEMS devices, namely a 500-600 GHz 3.3 bit phase shifter and a 500-750 GHz waveguide MEMS switch, a 0.02 dB/mm loss waveguide technology for the 220-330 GHz band with a number of implemented components including low-loss broadband 3Dcouplers, power splitters and integrated absorbers. Furthermore, the paper presents a high-performance filter technology with a 4-pole/2-transmission-zeros 1.85 fractional bandwith prototype implemented at 270 GHz with only 1.5 dB insertion loss. The paper concludes with an outlook of current devices under development at KTH.

I. 3D SILICON MICROMACHING FOR MICROWAVE DEVICES AND CIRCUITS

Silicon micromachining is mainly known as the fabrication technology for planar-circuit MEMS switches, which have demonstrated excellent RF performance [1], and already found their way as commercial products into mobile phones for tuning antenna matching circuits [2].

However, micromachining allows even for creating three-dimensional geometries which enables new, high-performance RF/microwave/THz device concepts, and integration with active or passive antenna arrays. Silicon is the preferred material for micromachining, since silicon micromachining processes are highly advanced and robust, it allows for fabricating micrometer-sized features and high-aspect ratio geometries with a height-to-feature-size ratio of over 110:1, silicon machining is a highly parallel batch fabrication technology where many thousands of devices can be fabricated simultaneously on silicon wafers with high product uniformity and high yield [3].

3D silicon micromachining has also enabled planar devices and circuits which even go beyond the performance of planar-MEMS RF circuits. For instance, a novel 2.5-D phase shifter concept for beam-steering developed at KTH for 75-110 GHz resulted in the return and insertion losses better than 12 and 4 dB, respectively, for any phase combination of a 4.25-bit phase shifter (98.3 °/dB; 715.6 °/cm, IIP3>49 dBm) [4]. Further examples of 3D micromachined devices for planar circuits are a near-ideal tuneable-capacitor concept with an unprecedented high Q-factor for a tuneable planar-circuit capacitor of 88 for 40 GHz [5], and a switchable coupler with very high directivity [6].

The first micromachined waveguide switch was implemented at KTH, based on a micromechanically reconfigurable surface, and resulting in 0.3 dB insertion loss and isolation of 40 dB at 50-75 GHz, despite being just 30 μm thick [7]. Such switches achieve basically the same performance as bulky, heavy rotary waveguide switches, but are of sub-mm size and can switch in the sub-ms range, thus being ideal for compact, low-weight reconfigurable circuits for satellite applications.

II. RECENT ACHIEVEMENTS IN 3D SILICON MICROMACHINED MICROWAVE DEVICES AND SYSTEMS

Recently, we presented a micromachined 3.3-bit phase-shifter integrated in a micromachined waveguide, operating at 500-600 GHz, in a collaboration with NASA-JPL [8]. Furthermore, together with NASA-JPL we published the first MEMS waveguide switch at 500-750 GHz, with 19-25 dB isolation and 2.5 dB insertion loss, with main application for switching reference loads in radiometric applications [9].

We developed a novel micromachined waveguide technology based on a double H-plane split which has only 0.02 dB/mm measured insertion loss in the 220-330 GHz band, which is the world’s lowest losses for a micromachined waveguide, and in the same order of better than even the best metal waveguides [10]. In this technology we implemented a couple of micromachined waveguide devices, including a micromachined, full-band 3-dB coupler at 220-330 GHz with only 3.2 dB worst-case insertion loss and very high directivity [11], as well as a 3-port power combiner for the same band [12]. The measurement of these micromachined waveguide components require high reproducibility of the measurement interfaces, and on-chip micromachined calibration standards, for which we have developed a micromachined waveguide absorber/attenuator technology [13]. In the same technology, we are currently implementing a micromachined antenna-array technology for beam steering through phased-arrays and

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multistatic radar applications, and a broadband OMT. The main reason for the low losses of all these components is the low sidewall roughness when using proper micromachining process design, far superior over any other fabrication technology, which is the main loss contribution factor when approaching submillimeter-wave frequencies. The low loss micromachined waveguide/cavity technology is excellently suited for high Q filters. We successfully implemented filter demonstrators above 100 GHz with outstanding performance, also due to the small and exact feature sizes possible to be implemented in silicon micromachining, which allows for accurately defining higher-order filters with different coupling structures. Recently we presented a prototype of a micromachined-cavity filter technology, with only 1.5 dB insertion loss and 18 dB return loss for a 4-pole and 2-transmission zero, 1.85% fractional bandwidth filter at 270 GHz, with measured cavity Q-factors in the order of 750-800 [14]. A 129-134 and 141-148 GHz diplexer for telecommunication links was recently implemented and will be shown at the workshop. Current, ongoing work comprises a filter bank for resolving spectral sub-lines of the water peak at 183 GHz.

III. CONCLUSIONS

This paper concludes, based on recent device prototypes, that 3D-micromachining may be a key enabling technology for high-performance millimeter and submillimeter-wave, reconfigurable devices and circuits. This technology is in particular suitable for satellite based telecommunication and radiometric sensing applications, due to low loss, low weight, high miniaturization, and reconfigurability.

IV. REFERENCES