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Excitation of a Double Corrugation Slow-wave Structure in Terahertz Range

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***Abstract*— In spite of the fact that the technology is constantly advancing, the realization of terahertz components is still heavily constrained by problems arising from technological limitations. As a result, the design of terahertz components still remains a challenging problem.**

In this work, an excitation problem of a terahertz double corrugation slow-wave structure is considered and practical realization of the structure using currently available technological processes is discussed. The parameters of the realized excitation structure are optimized for vacuum electronics applications while taking the technological constraints into account.

I. DESIGN CHALLENGES

A low loss double corrugation slow-wave structure has been proposed recently in [1], [2] for terahertz (THz) range vacuum electron devices. The structure provides a high interaction impedance, supports a cylindrical electron-beam, and is compatible with the existing fabrication processes. In spite of a number of mentioned advantages which make this structure promising for THz components, an issue of a proper slow-wave excitation still has to be addressed in order to realize the potential and ensure the applicability of the structure. The practical implementation of it requires a design of an efficient excitation scheme which is a challenging problem in the considered frequency range. The excitation part of the structure must be fabricated in the same technological process as the slow-wave structure in order to avoid consecutive alignment problems.

Due to the short wavelength of the electromagnetic signal, the physical dimensions of the excitation structure are inherently small. This imposes severe constraints on the error tolerance of the fabrication process and usually requires implementation of precise microfabrication technologies such as lithography. The implementation of the well established microfabrication "top-down" technologies leads to limitations in the structure realization allowing only two-dimensional patterns. Adding features and varying geometries in the third dimension (height) using a layer-by-layer approach is theoretically appealing but very difficult in practice. This would require processing in several steps by using the corresponding number of masks. From this, the better height resolution leads to more masks and processing steps. This considerably increases the fabrication costs, not to mention the alignment problems, which arise in multistage processing. Every mask should be precisely positioned with regard to the features already on the wafer in order to minimize the fabrication errors, which is a very challenging task taking into account the small size of the structure elements. In practice, this often leads to fabrication errors comparable with the size of the feature being fabricated, and therefore, the multistep fabrication must be avoided.

Another possibility to shape the structure in different dimensions is to turn it around with regard to the exposure direction, but this moves the problem to the post processing of the structure. The moving, and especially rotating, a miniature structure is very tricky. Moreover, the slow-wave structure along with the excitation part of it should finally be aligned with the precision of a few microns on the distance of several millimeters or even centimeters in order to allow for unobstructed electron-beam propagation in the device.

Another challenge is associated with increasing attenuation of electromagnetic signal in THz range. This imposes a significant additional constraint on the size of the excitation structure. The size should be as small as possible in terms of the electromagnetic wave propagation path in order to minimize the losses in the excitation region. On the other hand, the requirement for a broadband operation (the bandwidth of the excitation structure should be equal or wider than the bandwidth of the slow-wave structure itself) leads to long structures in terms of wavelength. This issue is particularly important when dealing with slow-wave structures where the electromagnetic wave propagation path is intentionally made longer than it would be in the regular wave-guiding structures. This tradeoff between the insertion loss and bandwidth requires a careful analysis and leads to an extensive optimization of the excitation structure profile.

II. Analysis and Realization of the Structure

A problem of a slow-wave mode excitation concerns a transformation of the fundamental mode of an external guiding structure, such as a rectangular waveguide, into operating mode of the slow-wave structure. Different types of slow-wave structures have different field distributions and therefore usually require specific excitation schemes. Nevertheless, a universal method for the design of an excitation structure can be implemented in our case which is based on tapering of the slow-wave structure parameters [3]. These parameters are associated with the physical dimensions of the structure. For the structure considered in this work, the double corrugation slow-wave structure, the tapering of the corrugation depth, corrugation period, corrugation width and the distance between two corrugations has been considered. The tapering of the corrugation depth was found to be the most effective excitation scheme in terms of insertion loss and the achieved bandwidth. Unfortunately this type of tapering is hardly compatible with the available technological processes for the reasons discussed above. The other types of tapering showed approximately the same performance, therefore the tapering of the distance between the two corrugations has been chosen for the realization of the excitation structure. The electron microscope picture of the realized structure is shown in Fig. 1. It has been fabricated using a LIGA process. The slow-wave structure itself is visible at the top of the picture. It consists of two corrugations with the height of 60 μm. The distance between adjacent corrugations linearly increases from 50 um to 254 um within 25 periods of the slow-wave structure until the corrugations merge with the walls of the rectangular waveguide.

The length of the slow-wave structure-to-waveguide transition is optimized for wide bandwidth and low insertion loss. The rectangular waveguide is then bends 90 degrees. The outer side wall has an opening to the drifting channel of the electron beam (not shown in the picture). In this arrangement the feeding waveguide is perpendicular to the slow-wave structure and the power can be fed away from the entrance path of the electron beam. Dimensions of the rectangular waveguide are 254 um × 80 um.

The estimated scattering parameters of the structure for back-to-back analysis are shown in Fig 2. Two coupling structures in back-to-back configuration introduce approximately 7 dB of total insertion loss at 1 THz. This corresponds to insertion loss below 4 dB for each excitation part. The frequency band of the transition where the return loss is better than 15 dB is from 0.79 THz to 1.03 THz. The upper cut-off frequency is related to the dispersion characteristic of the slow-wave structure itself.

As it was mentioned above, the structure has been fabricated using LIGA process and a parallel effort is already well underway to implement the same structure using more standard and lower cost UV photolithography implementing high resolution photoresists such as SU8, KMPR, and some others. Good results were obtained for regular periodic structures, while processing of single isolated pillars still needs to be optimized.

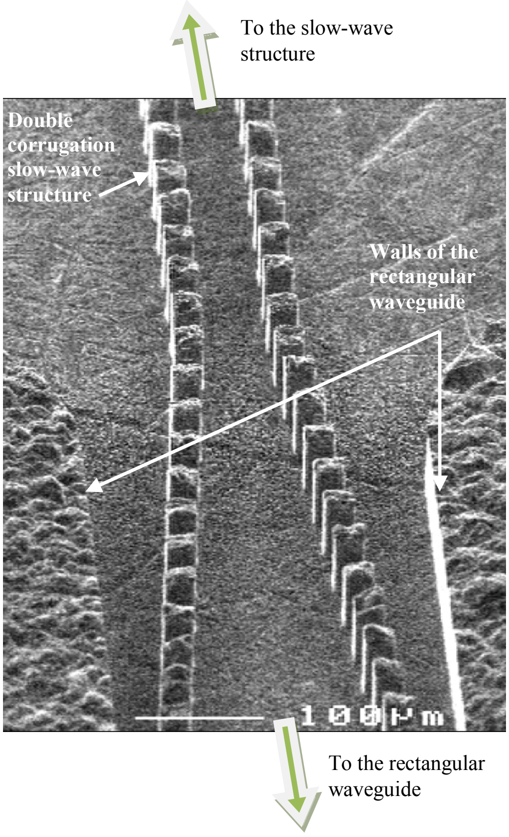

Fig. 1 Picture of the structure with the top cover removed

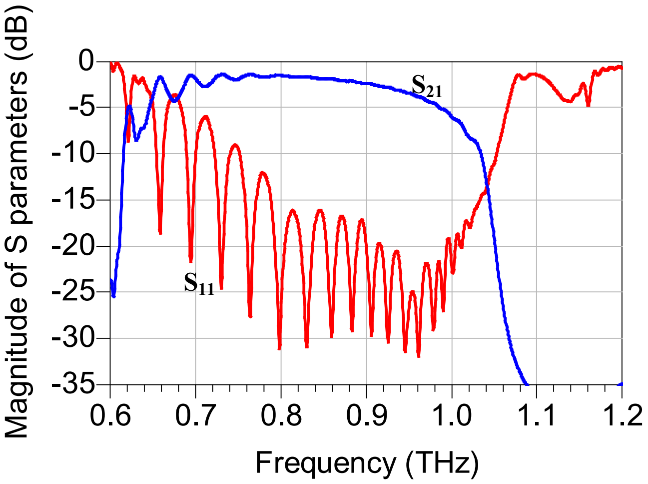

Fig. 2 Scattering parameters of the rectangular-waveguide-to-slow-wave structure transition in Fig. 1 (back-to-back configuration)

III. CONCLUSIONS

The design of excitation structures in the terahertz range is a challenging task due to the current technological limitations. The proposed excitation structure is based on tapering of the distance between the corrugations of the double corrugation slow-wave structure and offer the following advantages: the approach provides a wide operating frequency band; the leakage of the RF signal into the drift channel is minimized; the fabrication of the coupling structure is easy, as it is a direct continuation of the slow-wave structure.

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REFERENCES

[1] C. Paoloni, M. Mineo and A. Di Carlo, "Canale per fascio elettronico per tubi a vuoto", Patent Pending n.M09A13J4327.

[2] M. Mineo and C. Paoloni, "Design method for Double Corrugation Rectangular Waveguide THz Vacuum Amplifiers,"*Proceedings of the International Vacuum Electronics Conference IVEC2010*, Monterey, 18-20 May 2010, pp. 325 – 326.

[3] V. Zhurbenko, V. Krozer, M. Kotiranta, T. Rubæk, A. Durand and R. Marchesin, "Submillimeter Wave Antenna with Slow Wave Feed Line," *Proceedings of SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference*, November 2009, pp.388-392.