A Broad-Band Side Coupled mm-Wave Accelerating Structure for Electrons.

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Abstract

Modern micrometer etching techniques could be well suited for the fabrication of accelerating structures in the mm-wave region. But keeping fabricational tolerances within a few thousandths or tuning the structures is not at all obvious. Therefore we propose side coupled structures with a confluent π-mode which are expected to have large bandwidth, high group velocity and to be insensitive against errors. The proposed structures are planar, side coupled muffin tins. Three different geometries are investigated with coupling cells arranged symmetrically or alternately on both sides. Dimensions and basic RF parameters are given.

I. Introduction

Recently a double sided muffin tin has been proposed for electron acceleration in the mm-wave region [1]. The structure is planar and thus ideally suited for modern fabricational techniques like lithography and etching. On the other side it is not obvious to keep fabricational tolerances within a few thousandths or to tune such a structure. Also, due to the high losses per unit length one might get intolerably high temperature gradients. Therefore, one would like to operate the structure in a mode which has a high group velocity and which is the least sensitive to errors.

The $\pi/2$-mode fulfills most of the above mentioned requirements. But it has a low shunt impedance because of the close spacing of the irises. Better are, normally, double-periodic structures with confluence in the π-mode. They have high shunt impedance and high group velocity and are very insensitive to errors, especially if the dispersion relation is antisymmetric around the π-mode.

In the paper we investigate three different side coupled cavity arrangements, see fig. 1, with coupling cavities arranged symmetrically or alternately on both sides. All three geometries are planar and require no more complicated or more costly fabrication than the single periodic structure [1].

II. Choice of Geometry and Mode of Operation

The operating frequency is 120 GHz. This corresponds to a wavelength of $\lambda = 2,5$mm with typical cavity dimensions in the submillimeter range.

Looking at the mode of operation we have the option to use standing waves or travelling waves in π-mode, since the geometries are made confluent at π-mode, yielding a non vanishing group velocity and good mode separation.

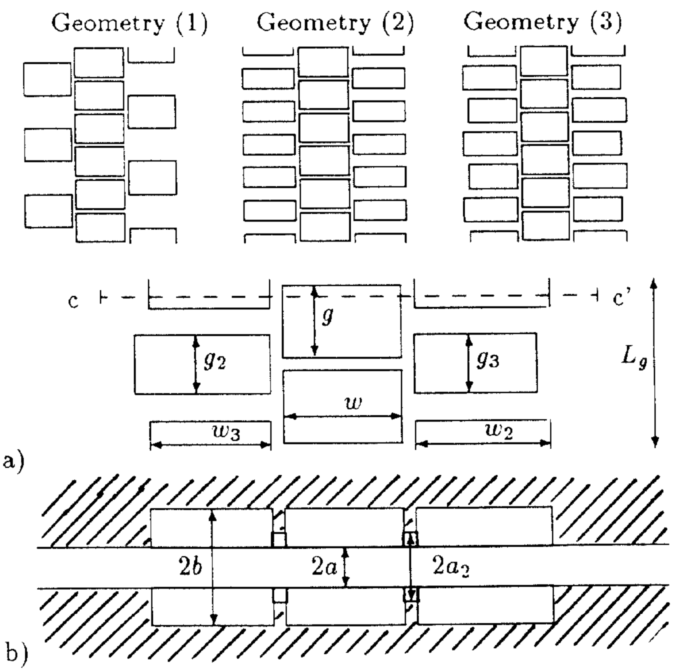


Figure 1: The double-sided muffin-tin structures
a) Top-view b) transverse cut of structure (3) (c-c')

Geometry: Three different confluent structures have been found. The structures have a geometric period lenght of $L_g = \lambda = 2,5$mm, and an electric period length $L_e = L_g/2$.

Structure 1 consists of two accelerating cavities and two coupling cavities per period L_g.

Structure 2 consists of two accelerating cavities and four coupling cavities per period.

Structure 3 consists of two accelerating cavities and four coupling cavities per period, with two different sizes of the coupling cavities.

The period length is given by $L_g = 2\pi/\beta = 2,5$mm. The other dimensions are chosen to obtain confluence. For 120

GHz the dimensions were found to be (all in mm):

$$\begin{array}{llll llll}
 & (1) & (2) & (3) & & (1) & (2) & (3) \\
a = & 0,3 & 0,3 & 0,3 & w_2 = & 1,65 & 1,78 & 1,95 \\
b = & w/2 & w/2 & w/2 & w_3 = & - & 1,78 & 1,75 \\
w = & 1,70 & 1,68 & 1,7 & g_2 = & 1,20 & 0,95 & 0,85 \\
g = & 1,05 & 1,05 & 1,05 & g_3 = & - & 0,95 & 0,85
\end{array} \quad (1)$$

The 'iris'-thickness t follows from the total length and the gapwidth g to $t = 0,2$mm. This is also the thickness of the walls between the accelerating and the coupling cells. To obtain a higher magnetic coupling the walls between the accelerating and coupling cavities have been cut to a depth $a_2 = 0,5$mm.

III. The basic RF Parameters

The RF parameters of the structures in Fig. 1 have been calculated with MAFIA [2]. The resulting parameters are ($\kappa = 56 \times 10^6/(\Omega\text{m})$) (Standing Wave):

Geometry		(1)	(2)	(3)
Q_0	=	2822	2593	2723
$r_0[\text{M}\Omega/\text{m}]$	=	260	246	266
$r_0/Q_0[\text{k}\Omega/\text{m}]$	=	92	95	98

The dispersion relations are given in Fig. 2. Note that the periodicity lenght is L_g, the phaseshift goes from 0 to 2π.
From the dispersion relations we get

		(1)	(2)	(3)
v_g/c_0	=	0,055	0,058	0,04
Bandwidth[GHz]	=	9,2	8,9	3,3
$\alpha[\text{m}^{-1}] = \frac{\omega_r}{2v_gQ_0}$	=	8,10	8,36	11,54

The following parameters depend on the number of cells per wafer. We have chosen $N = 56$ accelerator cells per wafer, giving a waferlength of $l = N\lambda/2 = 7$cm.

		(1)	(2)	(3)
$\tau = \alpha l$	=	0,57	0,59	0,81
$T_f[\text{ns}] = \frac{l}{v_g} = 2\frac{Q_0\tau}{\omega_r}$	=	4,3	4,1	5,9

The mode separation Δf is well above the theoretical need of f_r/Q_0. We could even have more cells on a wafer, if it wouldn't be limited by the available size:

		(1)	(2)	(3)
$\Delta f[\text{MHz}] = \frac{1}{2\pi L_c} v_g \frac{\pi}{N}$	=	118	124	86
$120\text{GHz}/Q_0[\text{MHz}]$	=	43	46	44

The dispersion diagrams need a little explanation:

In the case of geometry 1, the lower branch corresponds to fields in the accelerating cavities.

In the case of geometry 2, the lower branch also has the field in the accelerating cavities, the middle and upper branch have their fields in the side cavities. The middle branch has an odd field with respect to the transverse coordinate (dipol mode), the upper branch has an even field.

The case of geometry 3 is more difficult to describe: The field is in the accelerating cavities at the lowest 0 mode and one of the confluent 2π-modes. The field is in the greater coupling cavities (w_2) at the middle 0 mode and the lowest 2π-mode. The field is in the smaller coupling cavities (w_3) at the highest 0 mode and one of the highest 2π-mode. The accelerator mode jumps over the mode in the greater side cavities.

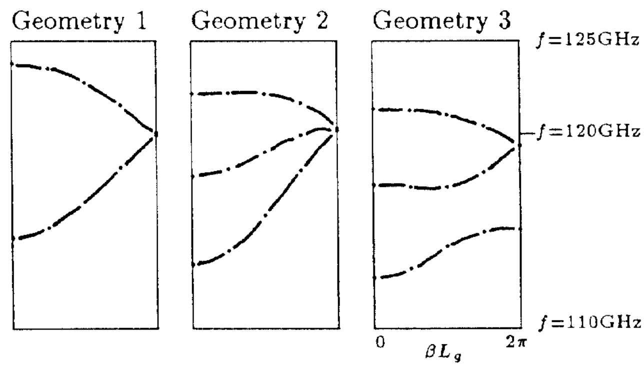
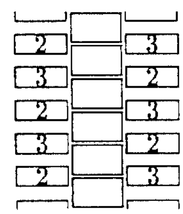
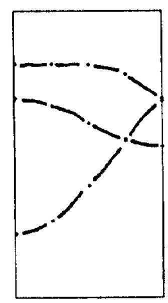


Figure 2: Dispersion relations of the structures (1)-(3)



Numbering the cavities of geometry 2 with all left coupling cavities named 2 and all right cavities named 3 leads to a dispersion relation as in fig. 2. Since geometry 2 has $w_2 = w_3$, we could renumber the cavities to a alternating structure. This leads to a dispersion diagram where the middle branch is swapped, as shown right. The dispersion diagram of geometry 3 can now be understood as the one of geometry 2 with the middle branch pulled down.



IV. Conclusions

Three different side coupled muffin tin structures have been investigated. All three geometries could be made confluent in the π-mode with only a slight reduction of the shunt impedance as compared to the single periodic structure [1].

Problems were the inevitable coupling between the coupling cells in the case of geometries (2), (3). It influences the interplay between modes in such a way that the dispersion relation could not be made very well antisymmetric around the π-mode. The geometry (1) has a quite antisymmetric dispersion relation but on the cost of deforming the fields in the main cells.

The bandwith is typically twice as high as for the single periodic structure. Further work should evaluate and compare the sensitivity against errors of the different geometries.

V. Acknowledgement

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References

[1] H. Henke, Y. W. Kang and R. L. Kustom, "A mm-wave RF structure for relativistic electron acceleration", Argonne National Laboratory, internal report ANL/APS/MWM-1, 1993

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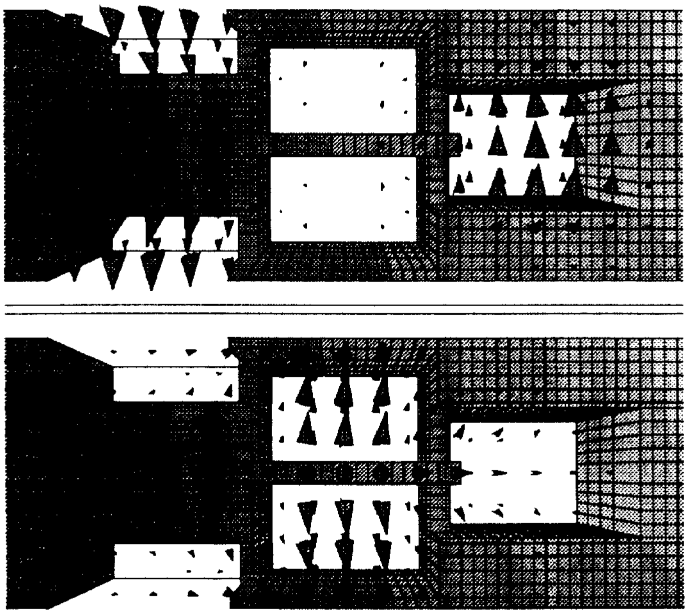

Figure 3: Confluent 2π-modes in structure (1)

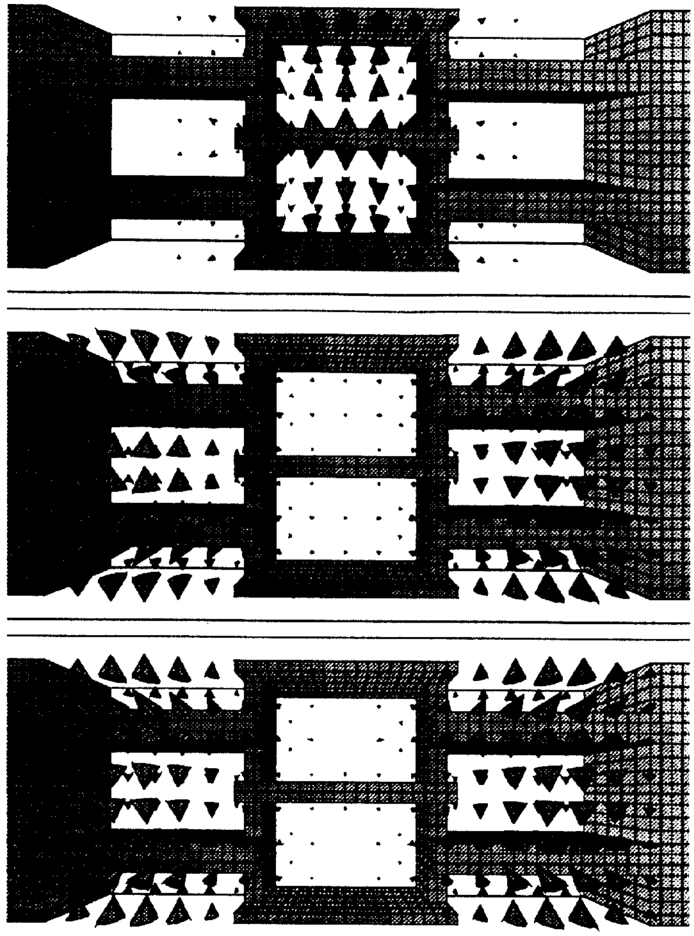

Figure 4: Confluent 2π-modes in structure (2)

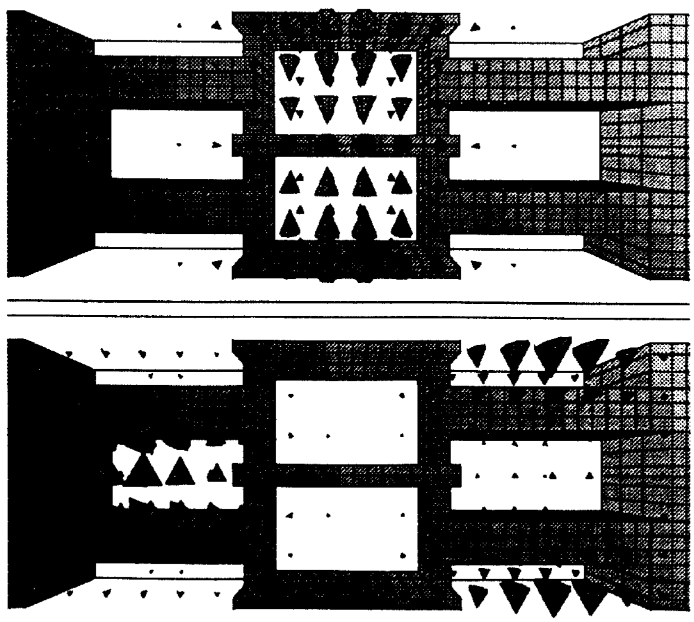

Figure 5: Confluent 2π-modes in structure (3)