Switchable directional filter based on defect-control by plasma discharge within a metallic EBG structure

J. Lo§, J. Sokoloff, and Th. Callegari

§ lo@laplace.univ-tlse.fr, jerome.sokoloff@laplace.univ-tlse.fr, thierry.callegari@laplace.univ-tlse.fr

Abstract

▪ Using plasma discharges to control partial propagation mode of an Electromagnetic Band Gap (EBG) structure presents interesting advantages: plasma discharge parameters (i.e. electronic density and collision frequency) are easily tunable to match the need in terms of microwave propagation. In this paper, our aim is to investigate the use of localized plasma discharges within a metallic EBG structure. We showed that plasma discharges may be used to compensate defects within an EBG, and thus, to design a switchable directional filter based on metallic EBG.

Objectives

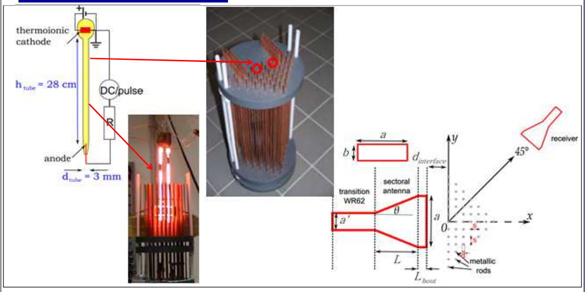
- comprehension of plasmas/microwave interactions within an EBG
- evaluate possibilities of EBG anisotropy control by plasmas discharge
- determination of the limit conditions for plasmas functionality in EBG based device

Framework

- transversal activity within 3EP / LAPLACE
- in the framework of PLASMAX project under Thematic Network for Advanced Research (RTRA STAE)

▪Authors would like to thank Leanid Simonchik (B.I. Stepanov Institute of Physics NASB) and Olivier Pigaglio (LAPLACE) for their precious help.

Experimental setup

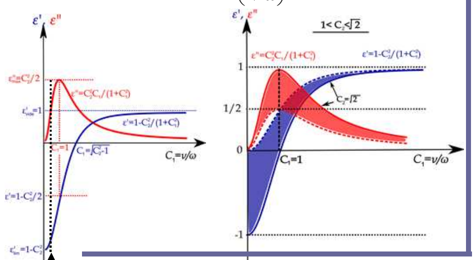


- EBG constructed with metallic rods in a square array
- step size : s = 10 mm ; rod diameter : d = 2 mm
- around 18 GHz : forbidden band in the 0x direction et authorized band in the diagonal direction (± 45°)
- wave source antenna (a = 50 mm, b = 20 mm, L = 45 mm, L_{bout} = 8 mm) placed at $d_{interface}$ = 5 mm
- plasma tube (40 Torr Ne) placed at *(x,y)=(0, ± s)* replacing initial rods
- receiver distanced 50 cm from central rod and measurement are done with Anritsu vector network analyzer from 0° to 90°

Plasma Drude Model

- hypothesis: homogeneous plasma column with complex permittivity:

$$\varepsilon_r(\omega) = 1 - \left(\frac{\omega_{pe}}{\omega}\right)^2 \frac{1}{1 - j\left(\frac{\nu_m}{\omega}\right)} = \varepsilon' - j\varepsilon''$$



We are here with :

$\varepsilon' = -1.92$ to -4, $\varepsilon'' = 1.47$ to 0.47 at 120 mA

$\varepsilon' = -1.29$ to -0.26, $\varepsilon'' = 0.68$ to 0.2 at 60 mA

Plasma experimental characterization

- plasma electronic density estimated by:

$$n_{pe} = \frac{j}{e.V_e} \quad \text{with current density} \quad j = \frac{4I}{\pi.D^2_{plasma}}$$

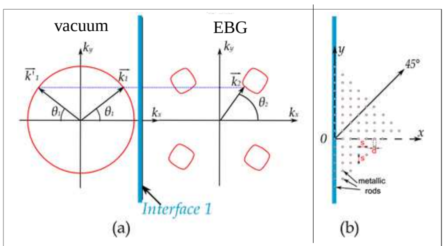
- electron drift velocity :

$V_e = \mu_e E$ with
- μ_e electron mobility from BOLSIG+
- E electric field in the discharge estimated $\sim V_{plasma}/h$

- collision frequency ν_m also from tabulated data in function of reduced field E/N in BOLSIG +
- precision is related to the temperature coefficient $\alpha_T = T_{gas}/T_{room}$

I [mA]	60			120		
	$\alpha_T = 1$	$\alpha_T = 2$	$\alpha_T = 3$	$\alpha_T = 1$	$\alpha_T = 2$	$\alpha_T = 3$
T_{gas} [K]	300	600	900	300	600	900
pressure [Torr]	40					
ν [s^{-1}]	$3.4\,10^{10}$	$2.5\,10^{10}$	$1.8\,10^{10}$	$3.25\,10^{10}$	$2.5\,10^{10}$	$1.8\,10^{10}$
$C_1 = \nu/\omega$ à 18 GHz	0.3	0.22	0.16	0.29	0.22	0.16
n_{pe} [cm^{-3}]	$1\,10^{13}$	$7\,10^{12}$	$5.2\,10^{12}$	$2.2\,10^{13}$	$1.5\,10^{13}$	$1.2\,10^{13}$
ω_{pe} [10^9 rad.S^{-1}]	178	149	129	264	222	195
$C_2 = \omega_{pe}/\omega$ à 18 GHz	1.58	1.32	1.14	2.34	1.96	1.73

Theoretical aspect : iso-frequency curve



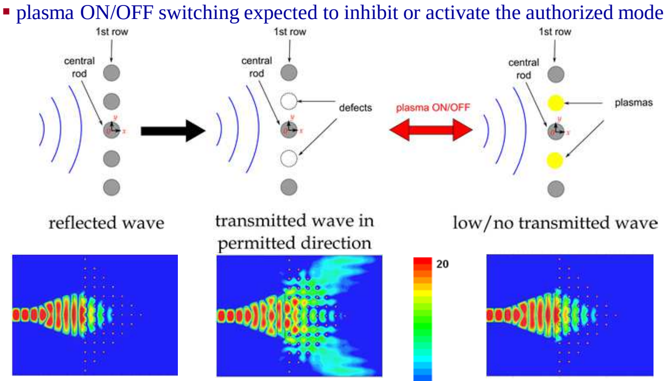
(a) : iso-frequency curve of the incident medium (isotropic) at left side a schematized iso-frequency curve for studied EBG

(b) : corresponding incident interface (Interface 1) is shown

- iso-frequency shows that EBG mode will only be excited if the incident wave vector respect the continuity at the interface
- reconfigurability idea :
  - ➔ incident wave directed to the forbidden wave direction
  - ➔ the coupling between wave source and interface is controlled by plasma discharge in order to modify the **effective** incident wave

Ansoft-HFSS simulation : E field distribution

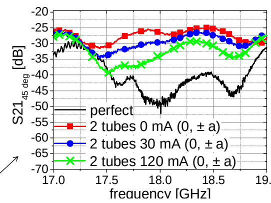
- plasma ON/OFF switching expected to inhibit or activate the authorized mode



perfect EBG configuration — EBG with double defect at *(x,y)=(0, ± s)* — EBG with plasmas at *(x,y)=(0, ± s)*

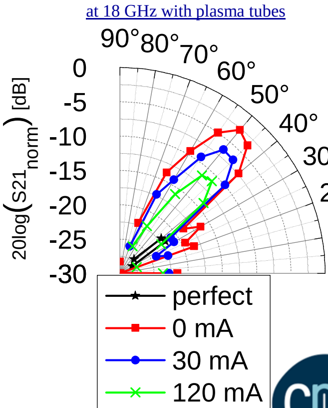
Microwave experimental measurements

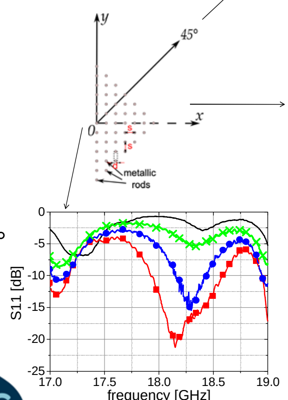
- Note : without EBG, the antenna maximal transmission at 0° is -23 dB at 50 cm
- up to 12 dB dynamic response is observed between 0 mA and 120 mA in the diagonal direction between 17.75 GHz and 18.75 GHz



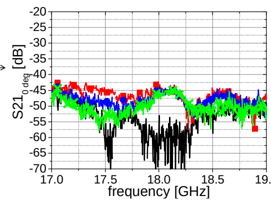
transmitted wave at 45°

Normalized experimental radiation diagram at 18 GHz with plasma tubes





retro-reflected wave



transmitted wave at 0°

Conclusion

- Feasibility of EBG controlled by plasmas is proven.
- Effective directional filtering device in the range of 18 GHz switchable and controllable by plasmas.
- DC plasma power consumption is however high up to 25 W for a power density of ~ 13 Wcm^{-3}

Université P. Sabatier
118, route de Narbonne, 31062 Toulouse cedex 9, France