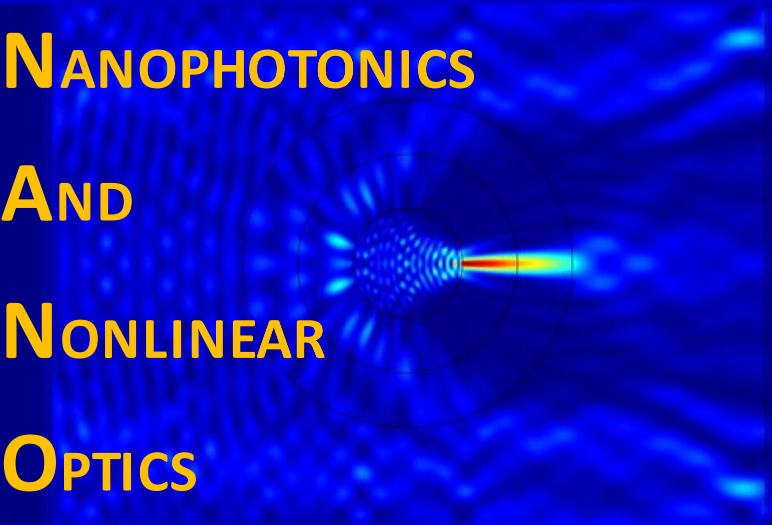


Presented at the 2011
COMSOL Conference in Boston

Simulation of Field Enhancement in Anisotropic Transition Metamaterials using COMSOL

Apra Pandey and Natalia M. Litchinitser
University at Buffalo, The State University of New York

Left-Handed Materials or Negative Index Materials

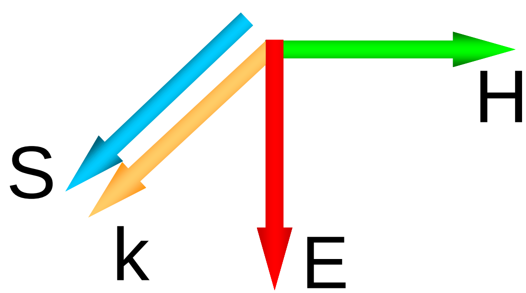
$$\left.\begin{array}{l} [kE] = \dfrac{\omega}{c}\mu H \\[2ex] [kH] = -\dfrac{\omega}{c}\varepsilon E \end{array}\right\}$$

$$S = \frac{c}{4\pi}[EH]$$

Poynting vector

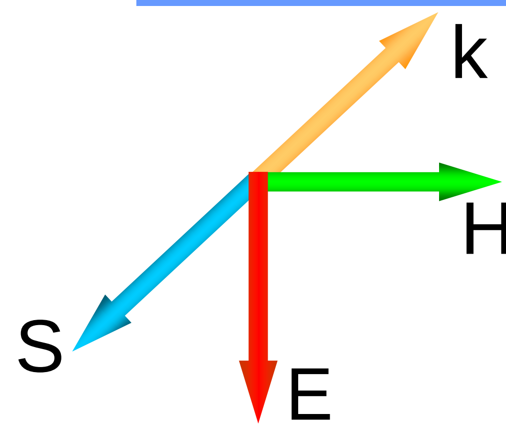
Right-Handed or Positive Index Material (PIM) if

$$\varepsilon > 0, \mu > 0$$



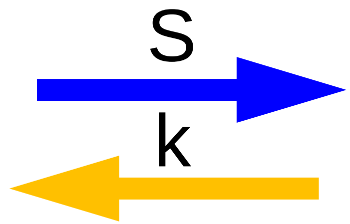
Left-Handed or Negative Index Material (NIM) if

$$\varepsilon < 0, \mu < 0$$



Negative Index Materials: definition

Materials with antiparallel k and S



Can be realized in

Double negative metamaterials

$$\varepsilon < 0, \mu < 0$$

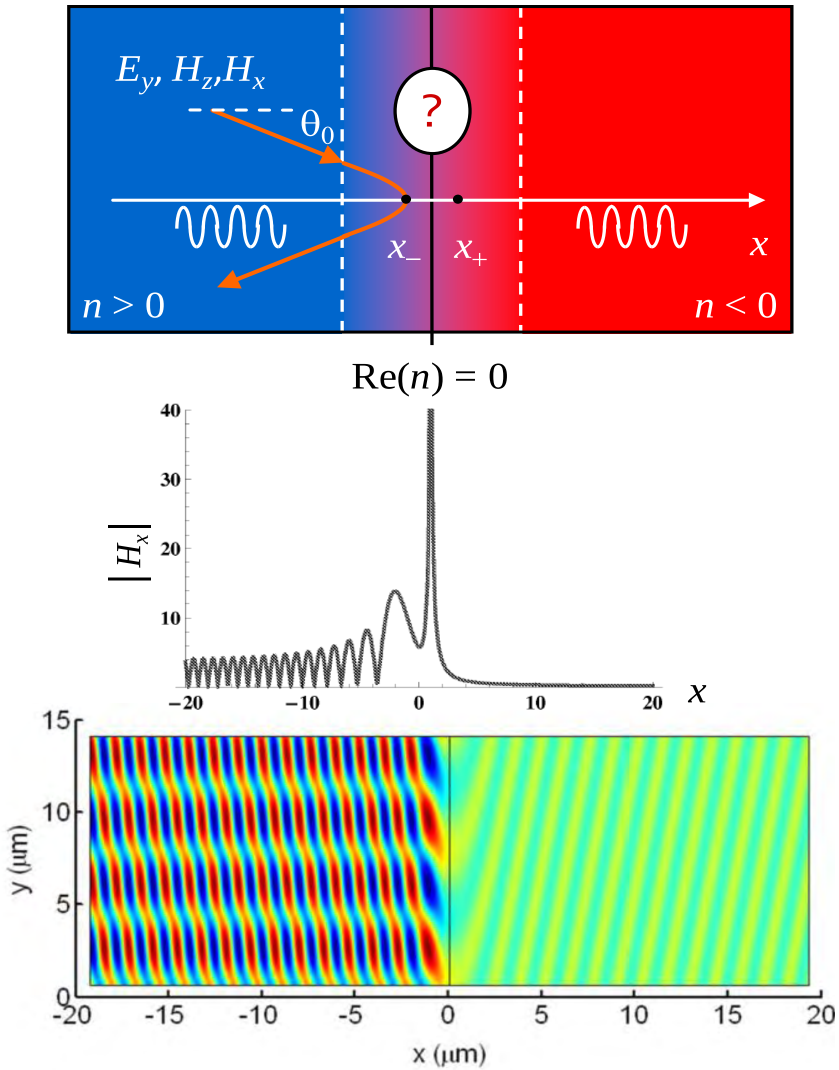
Anisotropic hyperbolic metamaterial waveguides

$$\varepsilon_x > 0, \varepsilon_y < 0$$

V. Veselago, Sov. Phys. Usp. 10, 509(1968)

D. R. Smith, D. Schurig, PRL 90, 077405 (2003)
R. Wangberg, J. Elser, E. E. Narimanov, V. A. Podolskiy, JOSA B **23,** 498 (2006)

Transition Metamaterials



Transition metamaterial is a graded-index metamaterial with refractive index varying from positive to negative values (or vice versa)

- Resonant electromagnetic field enhancement and resonant absorption at oblique incidence in the vicinity of the point where ε and μ *(or n)* change signs
- Potential applications: low-intensity nonlinear optics, polarization sensitive devices, wave concentrators

Spatial distribution of Electric field.

Litchinitser et al, OL 33, 2350 (2008), Kim et al., Opt. Express 16, 18505 (2008), Dalarsson, Opt. Express 17, 6747 (2009), Mozjerin, OL 35, 3240 (2010),Gibson, Opt. 13, 024013(5) (2011), Opt. Lett. (2011)

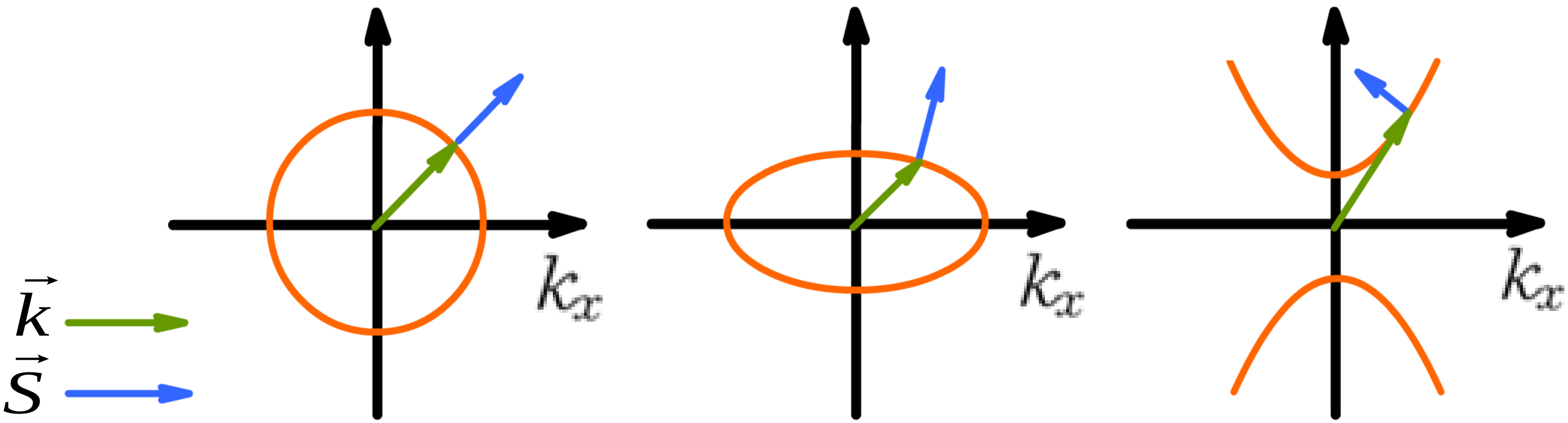
Motivation

- Previous studies focused on double-negative metamaterials, i.e. both dielectric permittivity ε and magnetic permeability μ were assumed to change sign

- However, designing μ is possible but challenging

- Our goal is to investigate propagation of electromagnetic waves in anisotropic graded-index metamaterials with $\mu = 1$

Anisotropic Materials



Isotropic material

$$\varepsilon_x = \varepsilon_y$$

Anisotropic material with $\varepsilon_x, \varepsilon_y > 0$

$$\varepsilon_x \neq \varepsilon_y$$

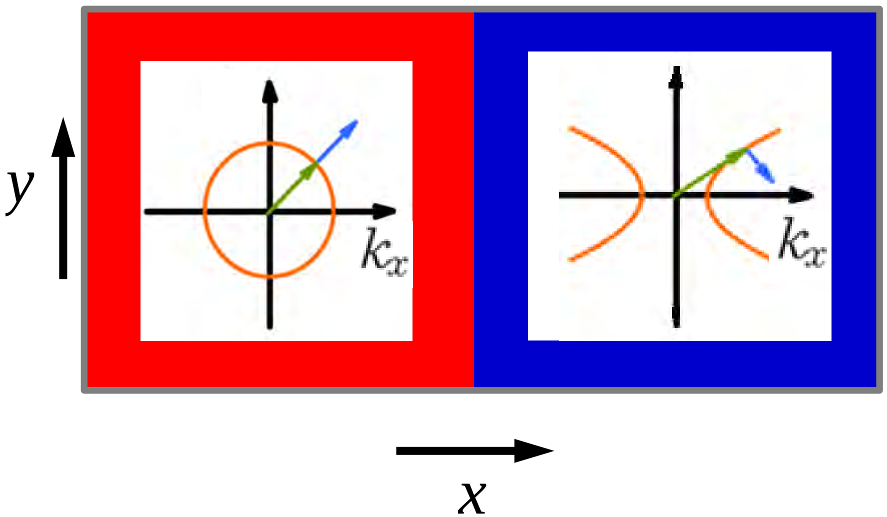
Anisotropic material with $\varepsilon_x > 0, \varepsilon_y < 0$

$$\frac{k_x^2}{\varepsilon_y} + \frac{k_y^2}{\varepsilon_x} = \frac{\omega^2}{c^2}$$

L. V. Alekseyev, E. Narimanov, Opt. Express 14, 11184 (2006)

Isotropic-Anisotropic Interface

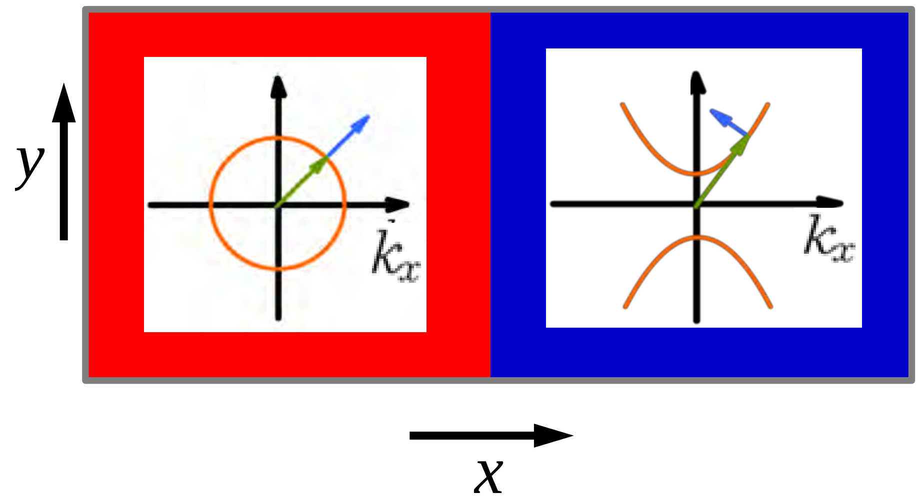
Case1: When ε_x changessign



$$\varepsilon_x = \varepsilon_y > 0$$

$$\varepsilon_x < 0$$
$$\varepsilon_y > 0$$

Case 2: When ε_y changessign

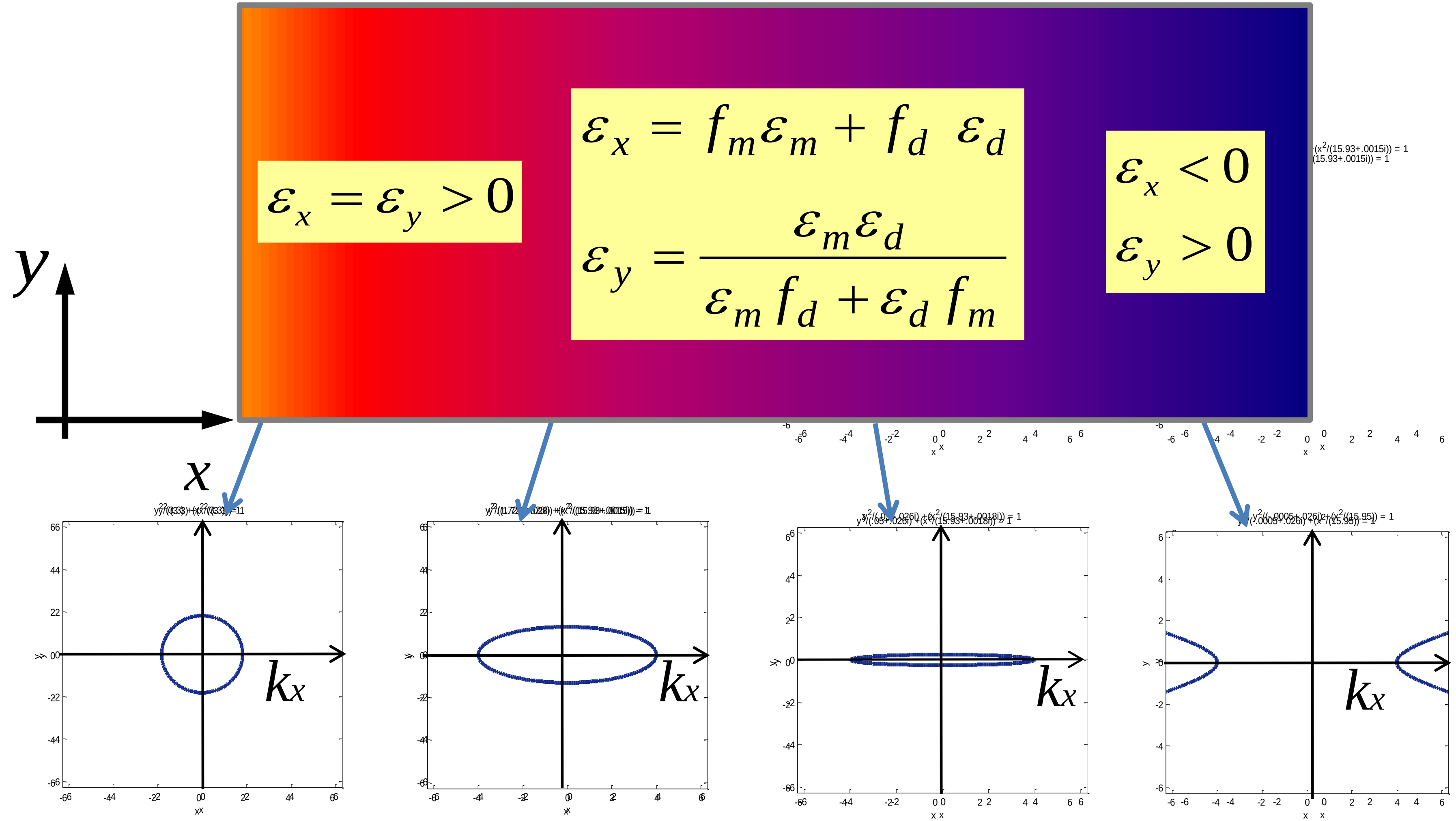


$$\varepsilon_x = \varepsilon_y > 0$$

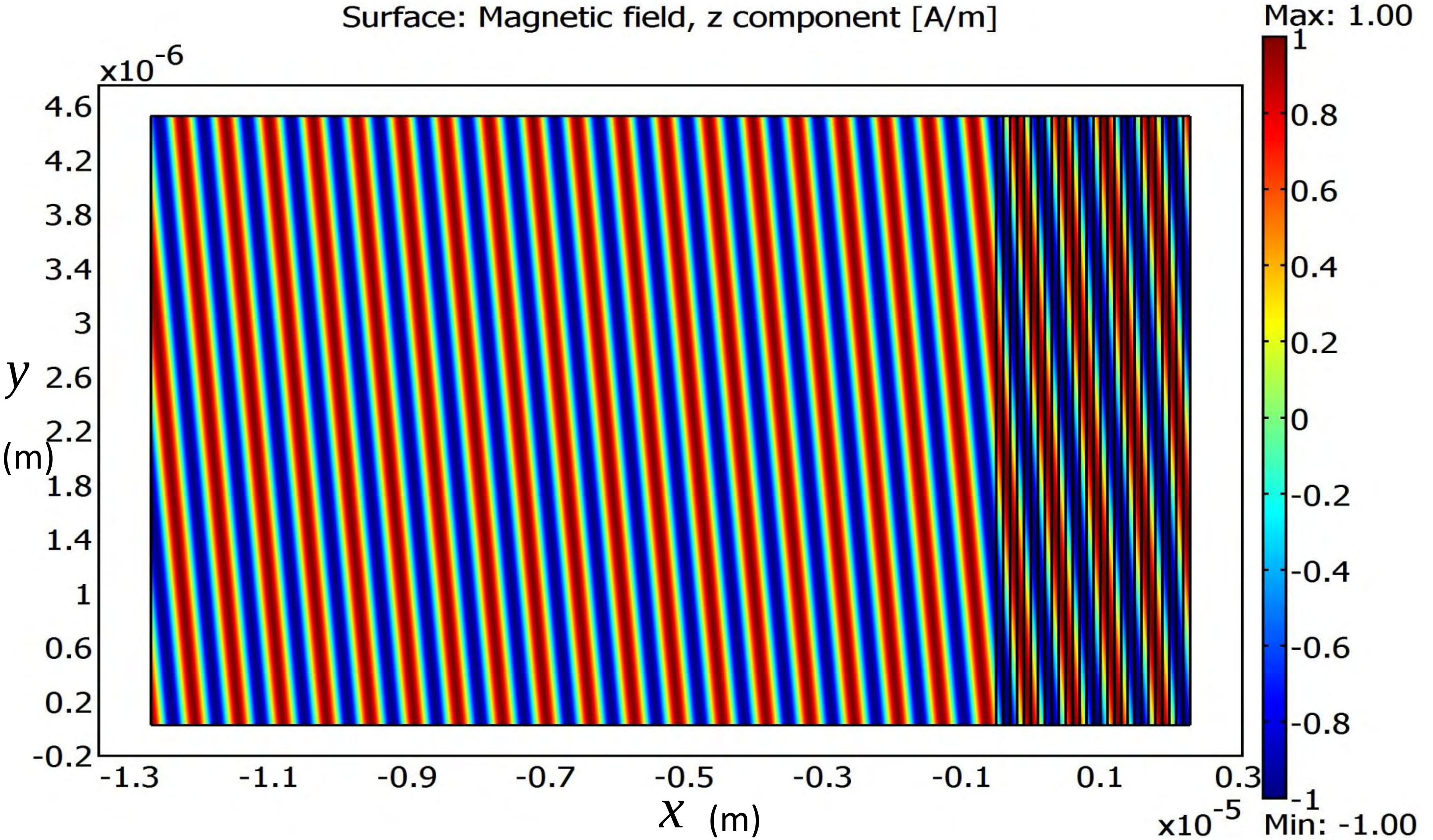
$$\varepsilon_x > 0$$
$$\varepsilon_y < 0$$

Evolution of Dispersion Relation

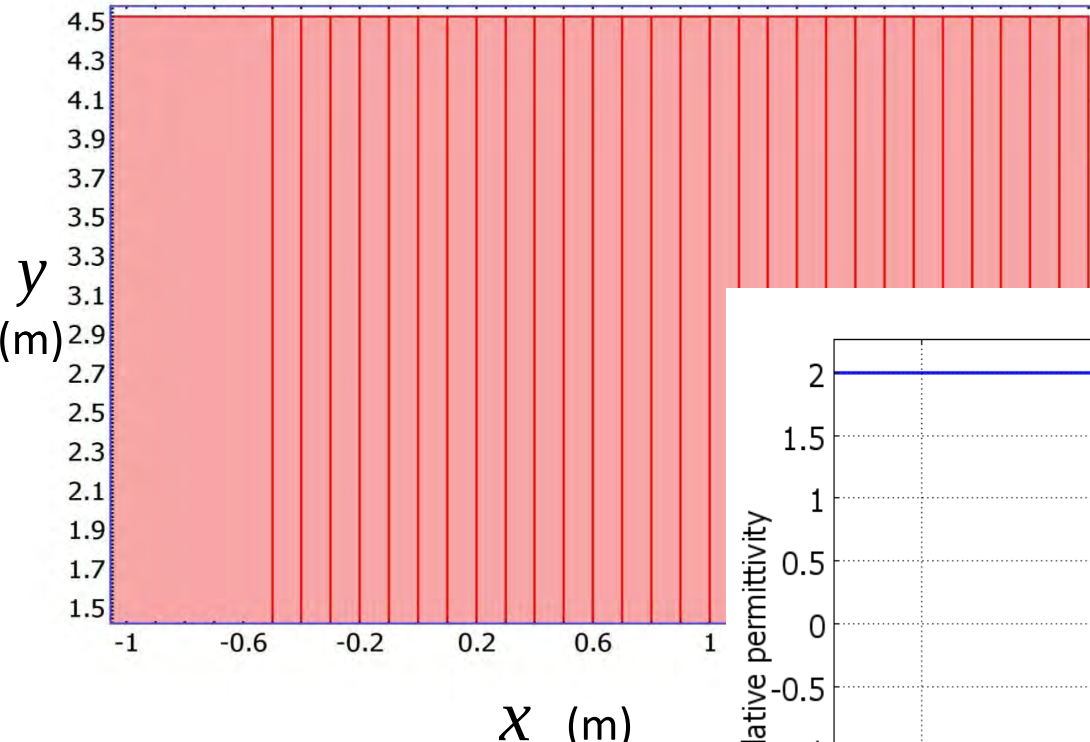
Case 1: ε_x is graded

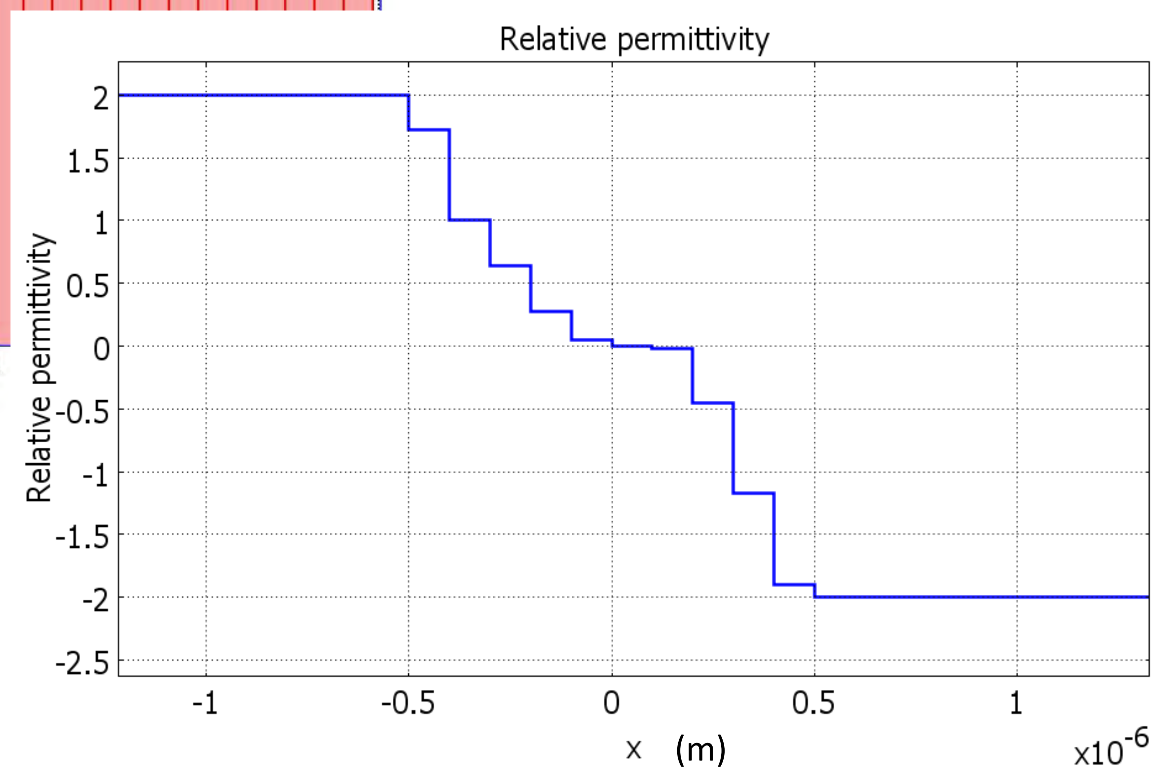


Oblique incidence in isotropic dielectric medium



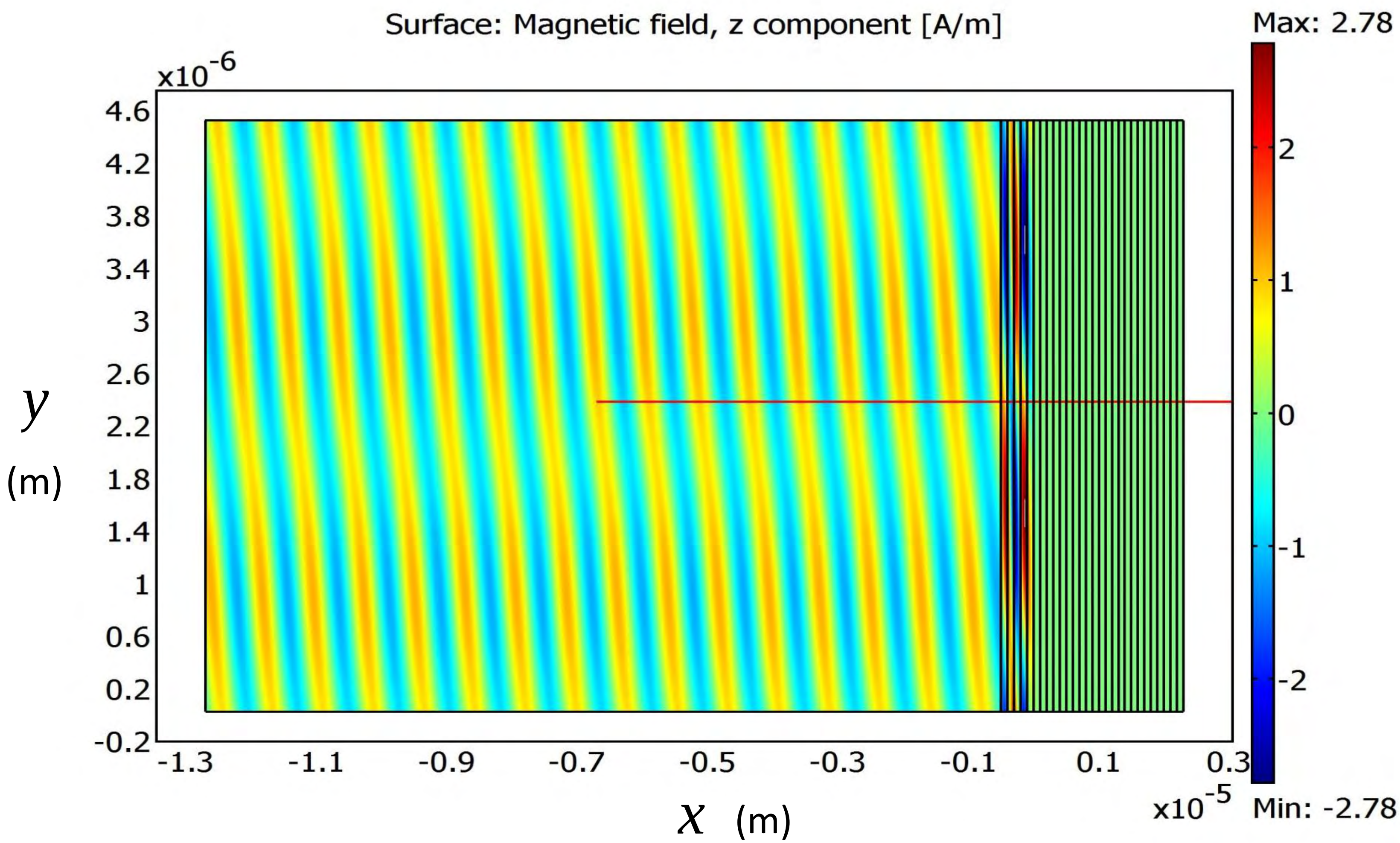
Design of Hyperbolic Transition Metamaterial





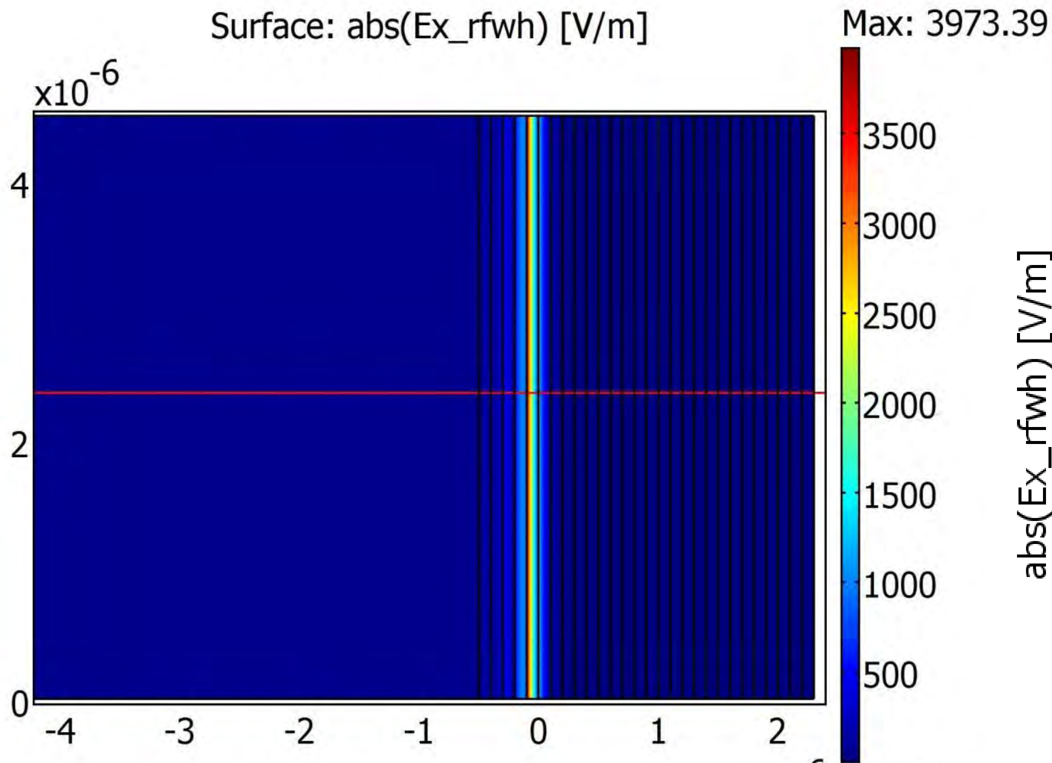
Oblique incidence

H_z



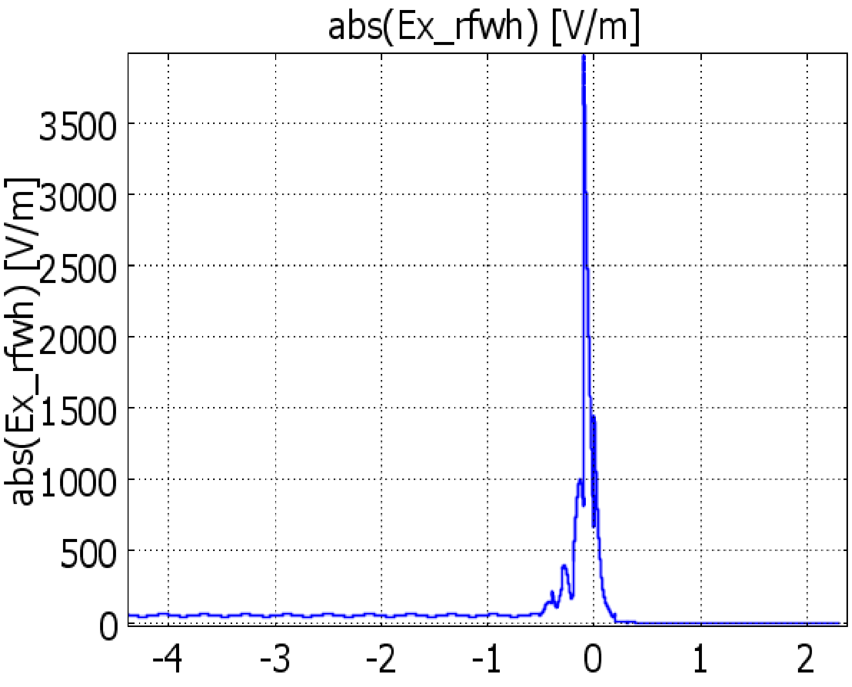
Enhancement in case of Oblique Incidence

$|E_x|$



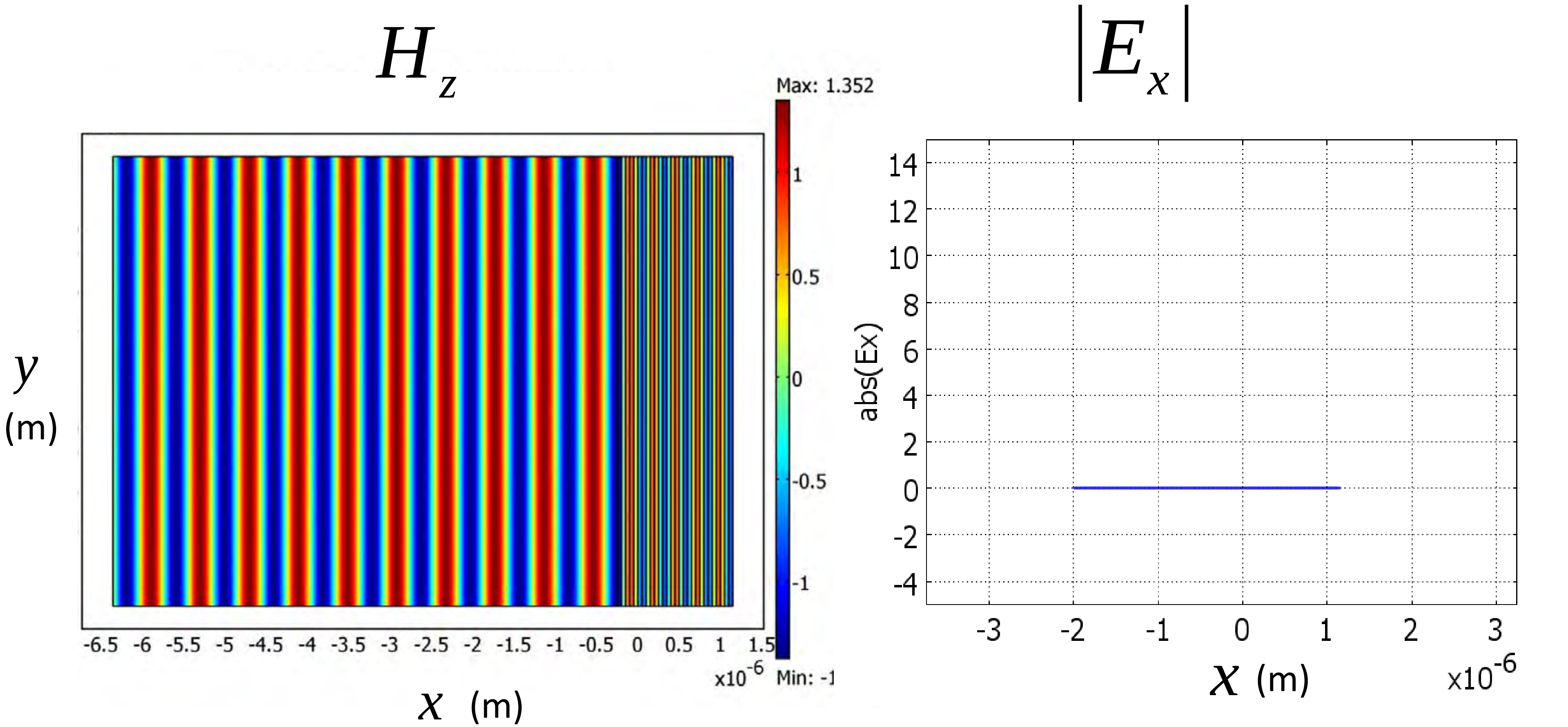
x (m)

$|E_x|$



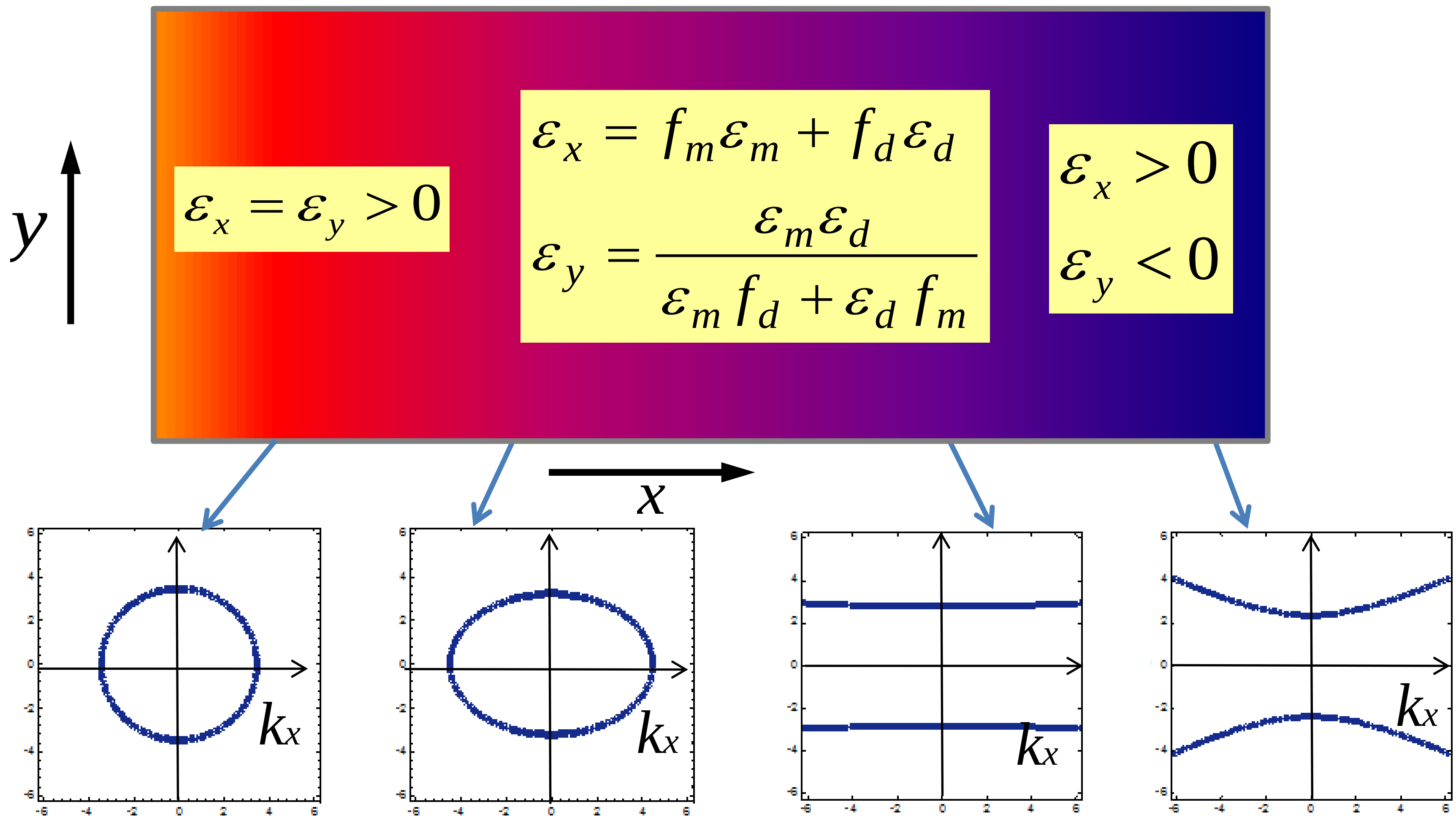
x (m)

Normal Incidence

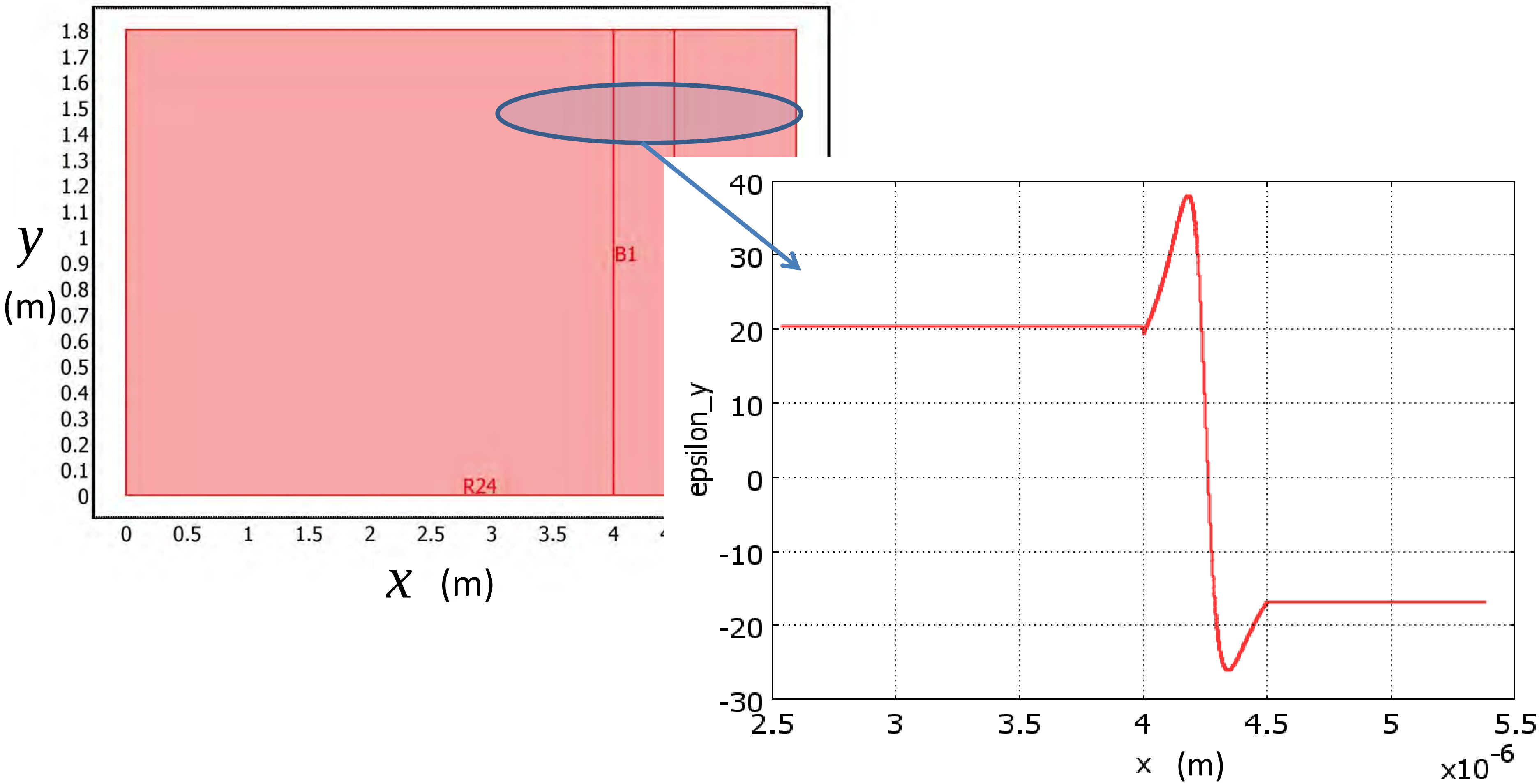


Evolution of Dispersion Relations

Case 2: ε_y is graded



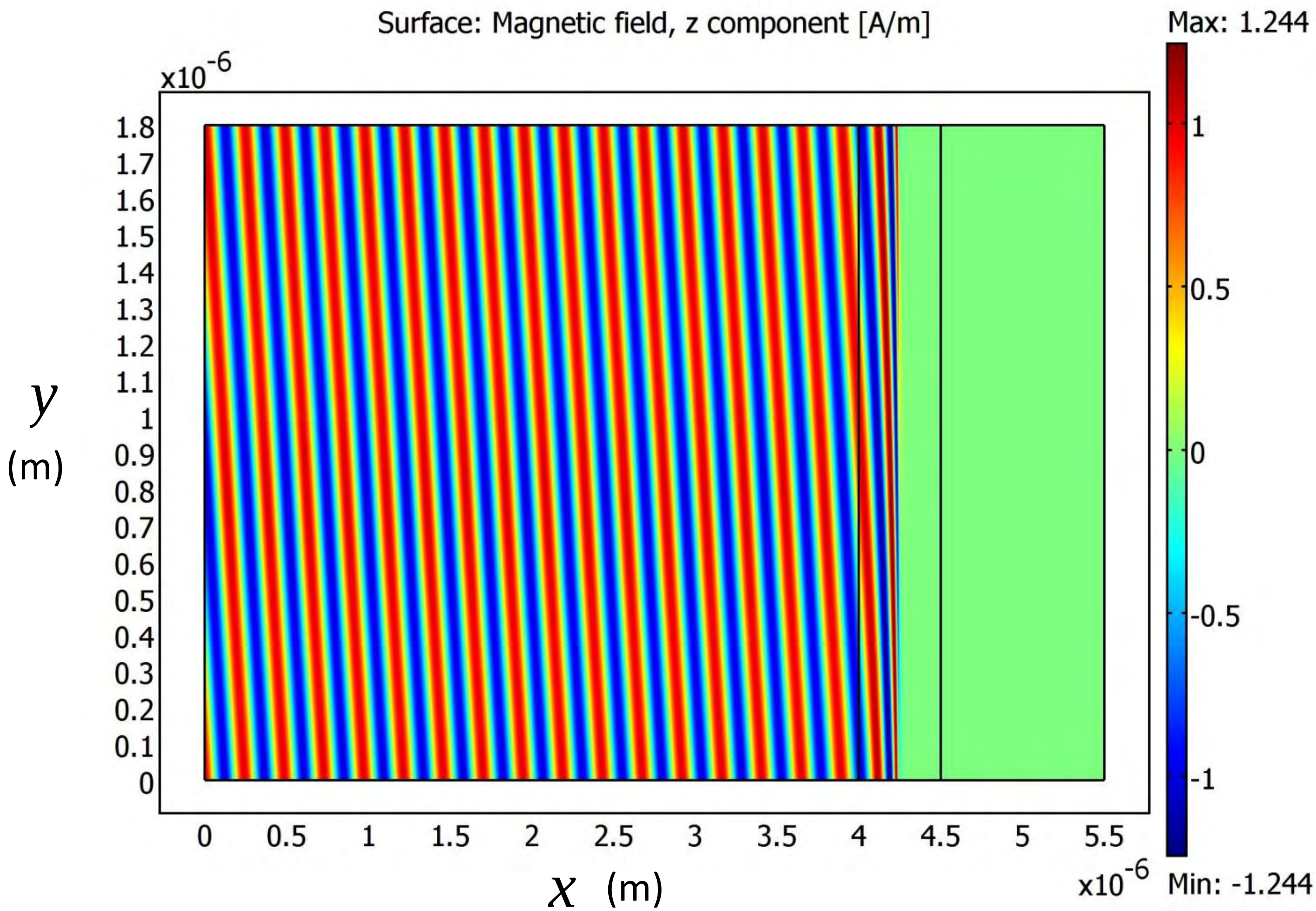
Design



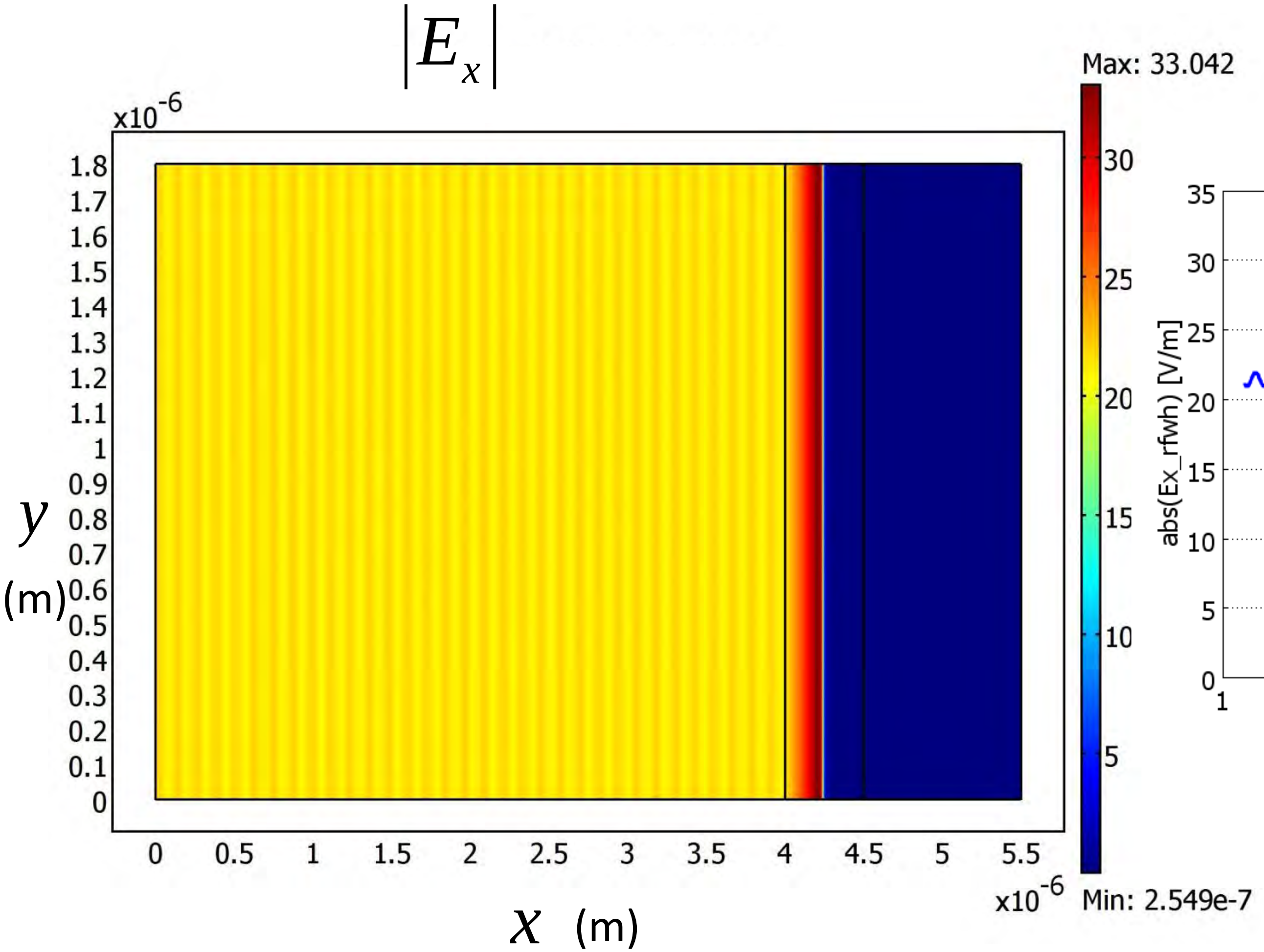
Real part of ε_y permittivity along x-direction

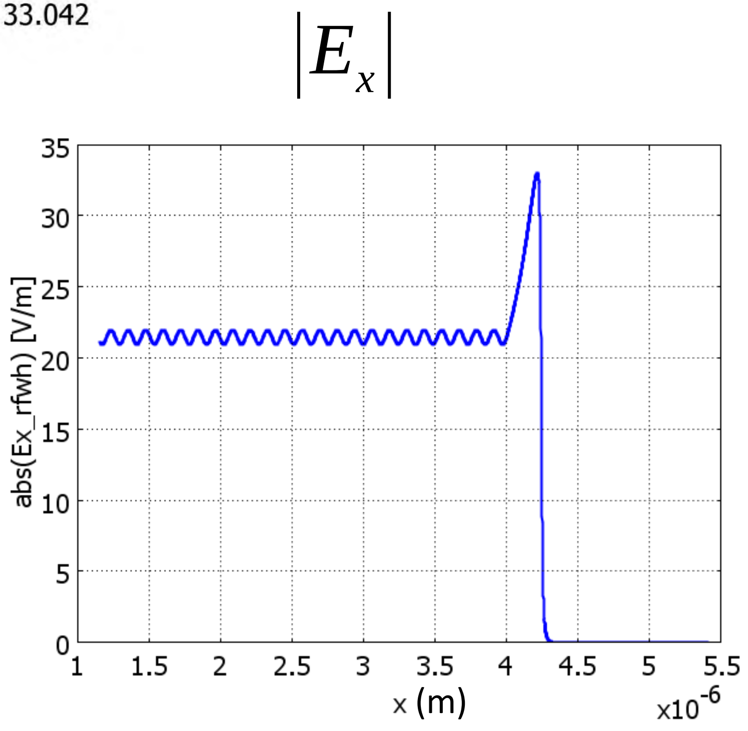
Oblique Incidence

$$H_z$$



Enhancement in Case of Oblique Incidence

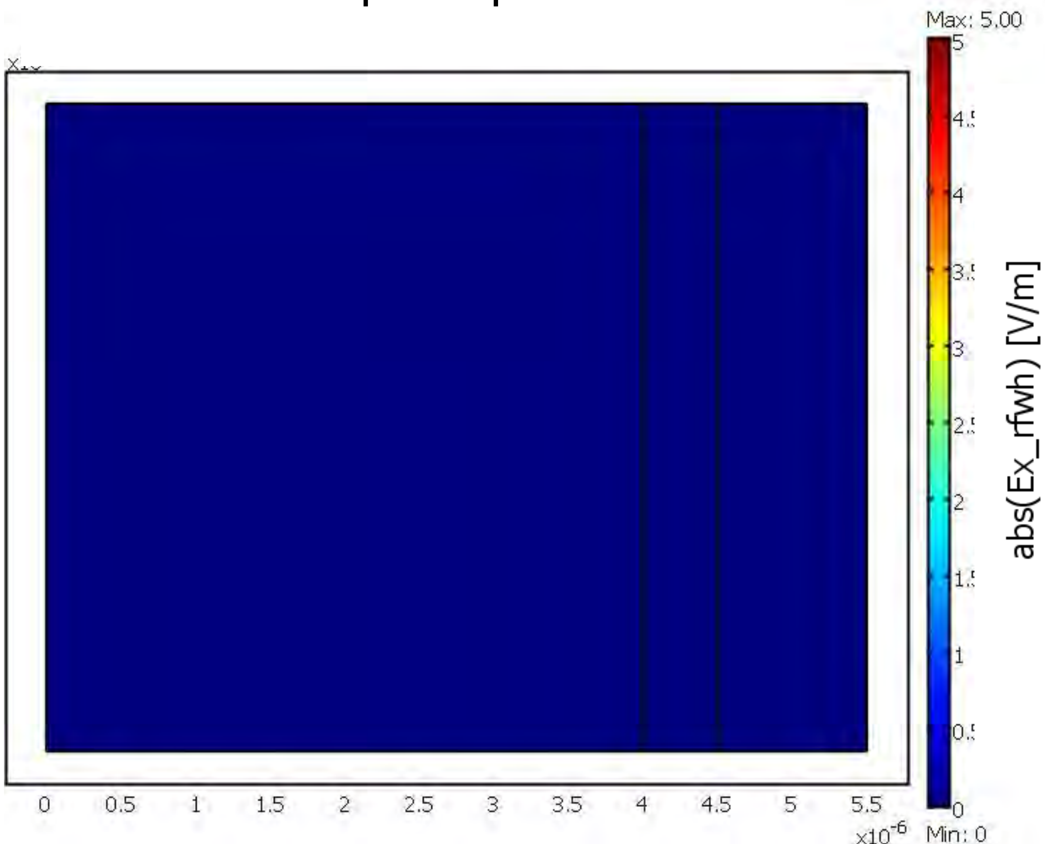




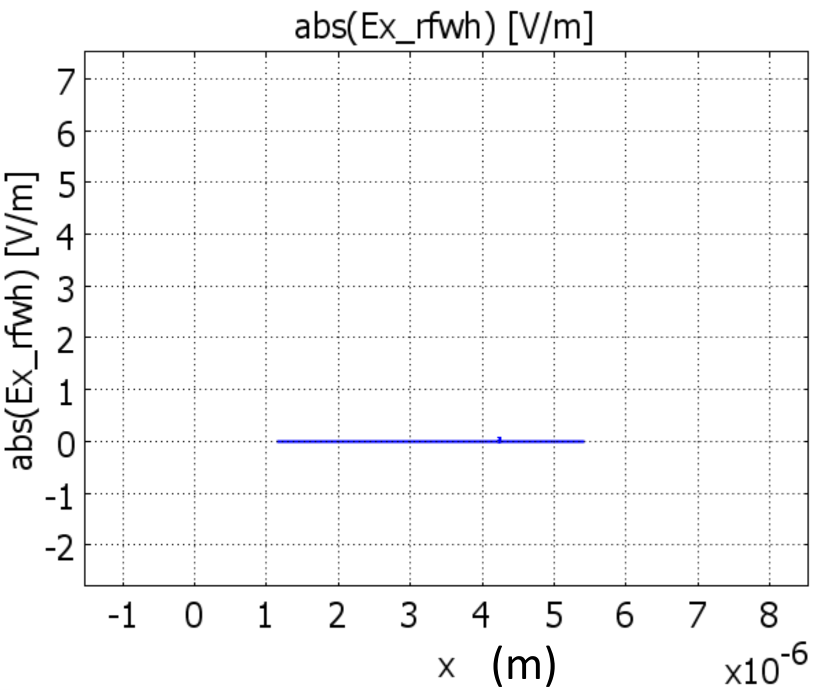
Normal Incidence

$$|E_x|$$

y



x (m)



Conclusion

- We investigated EM wave propagation in graded anisotropic metamaterial structures.
- Dispersion relation transitions from elliptical to hyperbolic
- We demonstrate enhancement of x-component of electric field in anisotropic transition region in case of oblique TM wave

Acknowledgements

- I would like to thank Gayatri Venugopal for helpful discussions.

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THANK YOU!