

UNIVERSITY OF BIRMINGHAM

University of Birmingham
Research at Birmingham

Optical Focusing via Epsilon-Near-Zero Plasmonic Metalens

Pacheco-Peña, V.; Navarro-Cia, Miguel; Beruete, Miguel

License:

None: All rights reserved

Document Version

Peer reviewed version

Citation for published version (Harvard):

Pacheco-Peña, V, Navarro-Cia, M & Beruete, M 2016, Optical Focusing via Epsilon-Near-Zero Plasmonic Metalens. in *META'16 in Malaga: The 7th International Conference on Metamaterials, Photonic Crystals and Plasmonics Proceedings*. META Proceedings: META'16 in Malaga, META Conferences, Spain, pp. 1898-1899, META'16, Malaga, Spain, 25/07/16.

[Link to publication on Research at Birmingham portal](#)

Publisher Rights Statement:

In addition, authors are encouraged to post and share their work online (e.g., in institutional repositories or on their website) at any point before and after the conference.

<http://metaconferences.org/ocs/index.php/META16/index/about/submissions#copyrightNotice>

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

Optical Focusing via Epsilon-Near-Zero Plasmonic Metalens

V. Pacheco-Peña¹, M. Navarro-Cía², M. Beruete^{1,3*}

¹ Antennas Group-TERALAB, Universidad Pública de Navarra, Campus Arrosadía, 31006 Pamplona, Spain

² School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, UK

³ Institute of Smart Cities, Public University of Navarra, 31006 Pamplona, Spain

*corresponding author: miguel.beruete@unavarra.es

Abstract-An ENZ metamaterial is engineered using a parallel plate plasmonic waveguide working near the cut-off of the transverse electric TE_1 mode. The ENZ region can be displaced to different wavelengths when the electrical width of the sandwiched dielectric is changed. Several converging lenses are designed at $\lambda_0 = 474.9$ nm with a focal length of $10.75\lambda_0$: a smooth concave, zoned and graded refractive index (GRIN) lens. It is demonstrated that the best performance in terms of the focal length and volume reduction is achieved with the GRIN design, achieving values of $10.23\lambda_0$ and $\sim 52\%$, respectively.

Within the framework of metamaterials [1], media with low permittivity, so-called epsilon-near-zero (ENZ), have become a prominent subfield of research due to their unusual characteristics such tunneling, supercoupling and energy squeezing [2]. These features have been demonstrated at microwaves [3] and also at optical wavelengths using waveguides close to the cut-off of the TE_{01} mode and also by metal-dielectric-metal multilayers, respectively [4], giving rise to different applications such as sensors[5] and lenses[6], [7].

In this work we use a plasmonic parallel plate waveguide in order to engineer an effective ENZ medium by working near the cut-off wavelength of the TE_1 mode under vertical polarization (electric field parallel to the waveguide) [8]. It is shown that the ENZ region can be tuned at different wavelengths within the optical spectrum when the width of the sandwiched dielectric of the plasmonic waveguide is changed. Several converging lenses are designed at $\lambda_0 = 474.9$ nm and evaluated numerically: a smooth profiled plano-concave lens, a zoned lens and a graded refractive index (GRIN) lens.

To begin with, the schematic representation of the waveguide is shown in Fig. 1(a) as an inset. Silica (SiO_2) is used as dielectric in between two silver plates (modeled as a Drude model). A vertically polarized planewave (E_y) is used to excite the structure in order to work with the transversal electric TE_1 mode. The propagation constant (β) of this structure is calculated by using the dispersion equation of a plasmonic waveguide (see [8]). This parameter has a clear dependence on the width of the dielectric slab (h_x) as can be corroborated in Fig. 1(a) where the complex value of β is shown for the case of a plasmonic waveguide with $h_x = 95$ nm and $h_x = 110$ nm. It can be observed that the cut-off wavelength moves to longer wavelengths when h_x increases, as expected. Around this inflection point β is close to zero, which is one of the properties of an ENZ medium. Therefore, it is possible to work within this region and emulate an ENZ metamaterial.

Based on this structure, we design several lenses working at $\lambda_0 = 474$ nm with different profiles as shown in Fig. 1(b-d), in order to focus an incoming planewave at a focal length (FL) of $10.75\lambda_0$. The numerical results of the normalized power distribution along the z -axis are shown in Fig. 1(e) for all the designs. The best performance is achieved for the GRIN design with a FL = $10.23\lambda_0$, while it is at FL = $14.4\lambda_0$ and FL = $11.3\lambda_0$ for the lenses in Fig.1(b) and (c), respectively. Furthermore, a reduction of volume of $\sim 52\%$ is achieved with the

GRIN lens, which is attractive from a practical point of view.

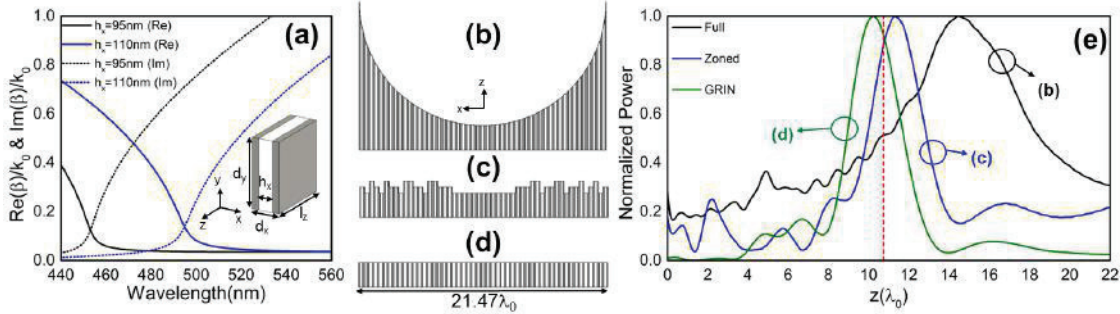


Figure 1. (a) Real (solid lines) and imaginary (dotted lines) parts of the propagation constant (β) normalized to the wavenumber in free-space(k_0) for two plasmonic waveguides with $h_x=95\text{nm}$ (black) and $h_x=110\text{nm}$ (blue). Schematic representation of the metalenses with profiles: (b) plano-concave, (c) zoned and (d) GRIN. (e) Normalized power distribution along the z -axis for the three converging lenses under study along with the design FL (red dashed line).

Acknowledgements, this work was supported by the Spanish Ministerio de Economía y Competitividad under contract TEC2014-51902-C2-2-R. V.P.-P. is sponsored by Spanish Ministerio de Educación, Cultura y Deporte under grant FPU AP-2012-3796. M. N.-C. is supported by a Birmingham Fellowship. M.B. is sponsored by the Spanish Government via RYC-2011-08221.

REFERENCES

- [1] R. Marqués, F. Martín, and M. Sorolla, *Metamaterials with Negative Parameters: Theory, Design and Microwave Applications*. Hoboken, NJ: Wiley, 2008.
- [2] M. G. Silveirinha, “Theory of Supercoupling, Squeezing Wave Energy, and Field Confinement in Narrow Channels and Tight Bends Using ϵ -Near-Zero Metamaterials,” *Phys. Rev. B*, vol. 76, 2007.
- [3] B. Edwards, A. Alù, M. E. Young, M. Silveirinha, and N. Engheta, “Experimental verification of epsilon-near-zero metamaterial coupling and energy squeezing using a microwave waveguide,” *Phys. Rev. Lett.*, vol. 100, no. 3, pp. 1–4, 2008.
- [4] R. Maas, J. Parsons, N. Engheta, and A. Polman, “Experimental realization of an epsilon-near-zero metamaterial at visible wavelengths,” *Nat. Photonics*, vol. 7, no. 11, pp. 907–912, Oct. 2013.
- [5] A. Alù and N. Engheta, “Dielectric Sensing in ϵ -Near-Zero Narrow Waveguide Channels,” *Phys. Rev. B*, vol. 78, no. 4, p. 15, 2008.
- [6] M. Navarro-Cía, M. Beruete, M. Sorolla, and N. Engheta, “Lensing system and Fourier transformation using epsilon-near-zero metamaterials,” *Phys. Rev. B*, vol. 86, no. 16, pp. 165130–1–6, Oct. 2012.
- [7] V. Torres, B. Orazbayev, V. Pacheco-Peña, M. Beruete, M. Navarro-Cía, and N. Engheta, “Experimental demonstration of a millimeter-wave metallic ENZ lens based on the energy squeezing principle,” *IEEE Trans. Antennas Propag.*, vol. 63, no. 1, pp. 231–239, 2015.
- [8] V. Pacheco-Peña, M. Navarro-Cía, and M. Beruete, “Epsilon-near-zero metalenses operating in the visible,” *Opt. Laser Technol.*, vol. 80, pp. 162–168, 2016.