
Substrate integrated waveguide based on ferromagnetic nanowires

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Keywords

Magnetic nanowires, ferromagnetic resonance, electromagnetic band-gap, planar microwave substrates, integrated waveguide

Text

In this work, we demonstrate the ability to design a wide range of compact and versatile microwave devices (filters, couplers, antennas, phase shifters, isolators, ...) in substrate integrated waveguide topology by taking advantage of precise manufacturing processes based on laser patterning for the controlled growth of nanowire arrays into nanoporous alumina template.

Two nanowired vertical walls and two metallic layers constitute a planar rectangular waveguide and force the microwave signal to propagate inside the alumina template. Placing additional various nanowired profiles inside the waveguide creates unconventional physical effects and allows to produce versatile and monolithic microwave components. This research paves the way towards the conception of a wide range of smart and versatile microwave devices offering immunity to radiation losses, excellent temperature stability and increased miniaturization compatible with high-frequency monolithic integrated circuits technology.

The substrate integrated waveguide (SIW) topology, introduced in the 2000s [1] has proven its efficiency for the realization of compact planar integrated microwave circuits. This technology exploits the possibility to create a shielded line of rectangular section by carefully placing vias, or metallic tubes, throughout the substrate entire height. The signal propagates easily inside the substrate surrounded by metallic layers, which protect it from external interferences and prevent radiation losses. This technique allows planar integration of active and passive components, and a wide variety of devices have already been proposed [2]. Using electrodeposited nanowires inside 100 μ m thick nanoporous alumina to form vias, it is possible to constitute an extremely thin substrate integrated waveguide to combine the advantages of nanowires and SIW components.

Exploiting the specific permittivity and permeability of nanowires arrays, the basic SIW structure is modified to achieve different types of devices (Figure 1). By properly placing nanowires arrays in the SIW cavity thanks to a laser patterning process [3], effects like the electromagnetic band-gap [4] or ferromagnetic resonance [5] are revealed and used to control microwave propagation. This innovative fabrication method allows us to control firstly the composition, height, and diameter of the nanowires and secondly, the location and the periodicity of nanowired areas.

Different devices have already been characterized. For example, the simple nanowired SIW have been realized. The cut-off frequency, created by the two metallic walls, have been observed at a frequency determined by the distance between the walls, as predicted by the theory [6]. Also, a SIW isolator has been produced: non-reciprocal propagation is induced by ferromagnetic resonance

taking place in a ferromagnetic nanowired band asymmetrically placed along the guide. In addition, a nanowired based SIW band-pass filter was created using electromagnetic band-gap (EBG) effect (Figure 2). Several nanowired strips placed across the guide create successive reflections and destructive interferences, decreasing significantly the amplitude of the microwave signal. The width and periodicity of the strips are calculated to make the propagation forbidden only at a precise frequency. Combining this effect with the cut-off phenomena, the microwave propagation is only permitted at a specific frequency range.

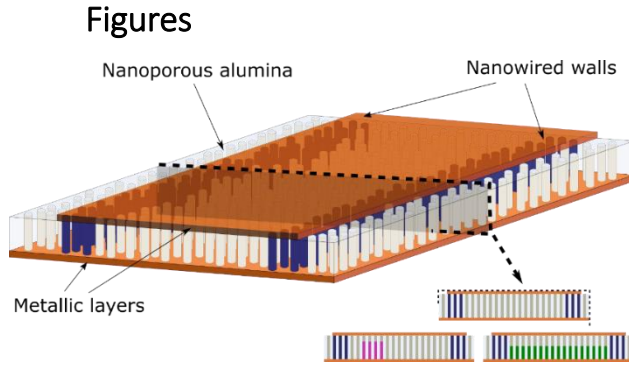


Figure 1. Schematic view of the waveguide integrated on a 100 μ m thick nanoporous alumina template. A laser-assisted process is used to produce patterned growth of vertically aligned nanowire arrays, to constitute the verticals walls of the guide, as well as to filled its cross-section with different nanowired profiles and materials.

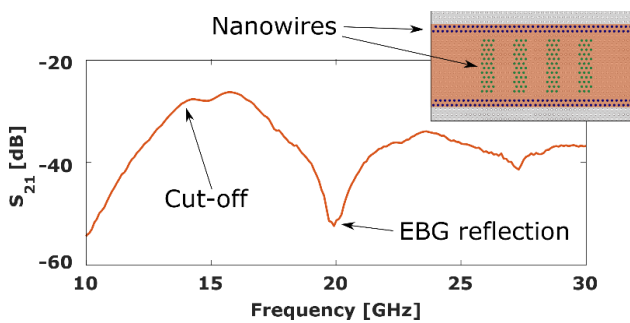


Figure 2. Measurement of transmission along a SIW electromagnetic band-gap (EBG) filter and schematic top view of the realized device. The four nanowired strips placed along the guide create filtering effect at 20 GHz and cut-off frequency is induced by effective nanowired walls of the SIW.

- [1] K. Wu, D. Deslandes, and Y. Cassivi, "The substrate integrated circuits - a new concept for high-frequency electronics and optoelectronics," in *Telecommunications in Modern Satellite, Cable and Broadcasting Service, 2003. TELSIKS 2003. 6th International Conference on*, vol. 1, Oct. 2003, pp. P-III-P-X vol.1.
- [2] M. Bozzi, A. Georgiadis, and K. Wu, "Review of substrate-integrated waveguide circuits and antennas," *IET Microwaves, Antennas and Propagation*, vol. 5, no. 8, p. 909, 2011.
- [3] V. Van Kerckhoven, L. Piraux, and I. Huynen, "A laser-assisted process to produce patterned growth of vertically aligned nanowire arrays for monolithic microwave integrated

devices,” *Nanotechnology*, vol. 27, no. 23, p. 235301, 2016. [Online]. Available: <http://stacks.iop.org/0957-4484/27/i=23/a=235301>

[4] A. Saib, D. Vanhoenacker-Janvier, I. Huynen, A. Encinas, L. Piraux, E. Ferain, and R. Legras, “Magnetic photonic band-gap material at microwave frequencies based on ferromagnetic nanowires,” *Appl. Phys. Lett.*, vol. 83, no. 12, p. 2378, 2003.

[5] M. Darques, J. Spiegel, J. De la Torre Medina, I. Huynen, and L. Piraux, “Ferromagnetic nanowire-loaded membranes for microwave electronics,” *J. Magn. Magn. Mater.*, vol. 321, no. 14, pp. 2055–2065.

[6] V. Van Kerckhoven, L. Piraux, and I. Huynen, “Substrate integrated waveguide isolator based on ferromagnetic nanowires in porous alumina template,” *Appl. Phys. Lett.*, vol. 105, no. 18, p. 183107, Nov. 2014.