Cut-Wire Metamaterial Resonator for Electromagnetic Energy Harvesting

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In this contribution, the power efficiency of a cut-wire metamaterial to harvest ambient electromagnetic radiation is studied in a frequency at about 3 GHz. Within the metamaterial, a nonlinear element is introduced to convert AC power to DC power. An equivalent electrical circuit is also proposed for an analytical purpose.

Energy Harvesting

Energy harvesting is the scavenging for ambient energy to power electrical devices. This ambient energy comes from different sources (vibrations, solar energy, thermal energy, salinity gradient ...) and is transformed through various transduction mechanisms such as chemical, pyroelectric, piezoelectric and electromagnetic induction. The first two ones involve chemical or heat reactions (e.g., solar panels), the last ones involve rigid or flexible dynamical structures (e.g., windmills, hydroelectric turbines). Several contributions have been published centered on the design of nonlinear analysis of piezoelectric and electromechanic energy harvesting systems [1-4] because of the high energy density of mechanical vibrations its provide. Nevertheless, these systems can not operate for energy harvesting at high frequencies like electromagnetic energy (MHz, GHz and THz). To handle this situation, scientists found in metamaterials a way to harvest electromagnetic radiation [5-7]. Even if the energy density is not the same as in piezoelectric energy harvesting, the size of energy harvester is considerably reduced and this enhances their applicability in several fields.

Metamaterials

Metamaterials are artificial materials that show peculiar behaviour that is not observed in natural material. To enhance the functionality of metamaterials, several approaches to realize nonlinear metamaterials have been introduced, e.g., by inserting a nonlinear lumped element inside the metamaterial, by incorporating the metamaterial in a nonlinear host medium, or by locally quenching the superconducting state in a cryogenically cooled niobium meta-atom. The realization of nonlinear metamaterials spurred a new research line within the field of electromagnetism for applications in superlenses, waveguiding and, more recently, in energy harvesting.

Enhanced Energy Harvesting Using Nonlinear Metamaterials

We are working on the improvement of the efficiency of electromagnetic energy harvesting using cut-wire metamaterials. The metamaterial device we propose is shown on Fig. 1. The unit cell of the energy harvesting metamaterial is submitted to the E-field radiation which is normal to the plane containing the metamaterial. The cut-wire metamaterial is designed at a frequency of 3 GHz, and the analytical calculations using an equivalent electrical circuit allow us to observe that the maximum power harvested is around the resonance frequency of the material as shown in Fig. 2. Therefore, we can play analytically with the parameter sizes of the device in order to optimize the design of the energy harvester system.

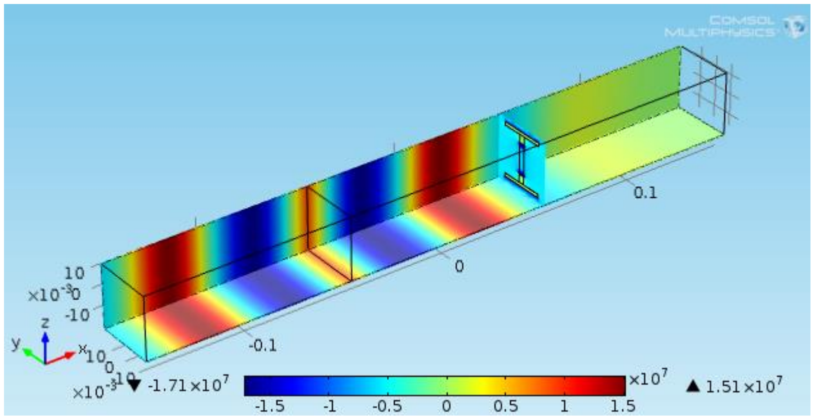

Fig. 1: The unit cell of the energy harvesting metamaterial and setup of the numerical simulation

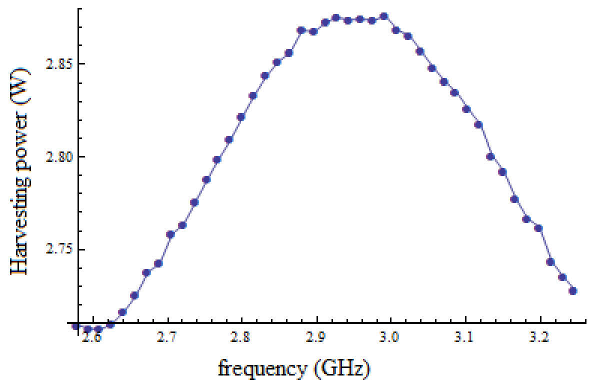

Fig. 2: Harvesting power as function of the frequency of the electromagnetic radiation.

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Temperature Stability and Aging Prediction of the Draw Tower Gratings (DTGs)

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In this paper, we experimentally perform the temperature stability tests for the draw tower gratings (DTGs) from 373K to 723K. These results have been successfully adopted into the proposed mathematical aging model in the Ultraviolet (UV)-inscribed gratings. In the end, a long-term operation of the DTG samples can be predicted by using this model.

Introduction

Draw tower gratings (DTGs) are manufactured during the fiber drawing process prior to applying the coating in order to preserve the mechanical strength of the DTGs. From the point of view of FBG based optical fiber sensors, the stability of the reflected optical power and the Bragg wavelength will be an important parameter to determine the sensing performance of the sensor. T. Erdogan proposed an accelerated aging experiment method to stabilize temperature induced refractive index changes and introduced an empirical approach to construct the aging prediction model in UV-inscribed gratings [1]. Therefore, we will systematically perform this accelerated aging experiment on our DTGs. Then, the aging prediction model of our DTGs for long-term operation can be constructed by using the aging curve approach.

Sample preparation and aging results

In this accelerated aging experiment at different elevated temperatures, around two to three DTG samples with Ormocer®-T coating [2] were directly inserted in a tube furnace (9173, Fluke) for 3000 minutes. At the same time, the optical interrogator (SM125-500, Micron Optics) was used to monitor the variation of the reflected power and the Bragg wavelength. The initial reflectivity of our DTGs was measured at room temperature by the cut-back method and was used to normalize the variation during annealing as we have shown in the figure below. Therefore, the aging curves of the different DTGs are shown in Fig. 1.

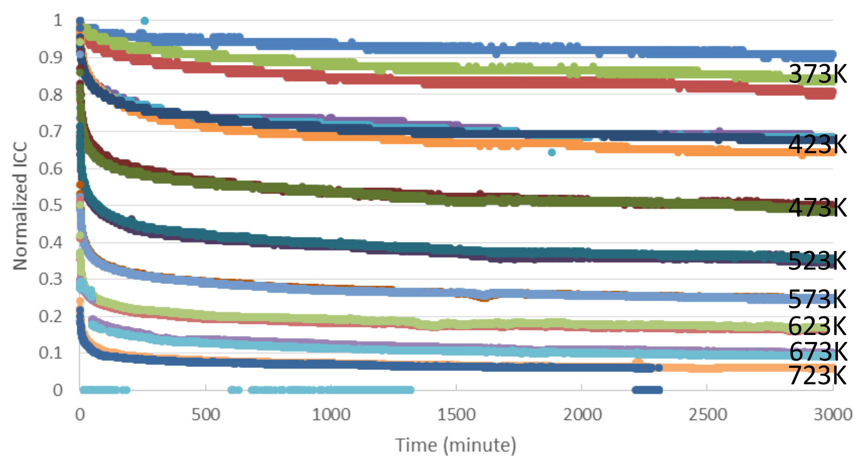

Fig. 1: The accelerated aging test results on DTGs.

Here, the aging result has been converted into integrated coupling constant $(ICC = \tanh^{-1}(\sqrt{R}))$ versus time [3]. For each annealing temperature, the reflectivity will experience a sudden drop at the beginning and then gradually approach to a stable value. This drop becomes faster and more significant at elevated temperatures. This behavior also matches the concept of demarcation energy where the unstable component