Modeling Optical Power Loss In Permalloy Film: Thermoelectric Gradient Simulations In Nanostructures

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Abstract

Laser-induced photovoltage in ferromagnetic thin films is often explained by magneto-thermoelectric effects such as the anomalous Nernst effect (ANE). ANE appears when thermal gradients interact with magnetization. While power loss in flat films can be estimated analytically, numerical simulations are helpful when geometries are complex, or heat conduction must be considered. In this study, we use COMSOL RF simulations to calculate the electromagnetic power loss in a 35 nm permalloy film on glass. The results show that all wavelengths in the visible range give a crossover depth near 22 nm, which agrees with known skin-depth behavior. These results can support future simulations of temperature gradients and photovoltage in modulated structures.

The modeled structure consists of a 35 nm $Ni_{80}Fe_{20}$ (permalloy) film on a flat glass substrate, illuminated through air by transverse magnetic (TM or p-polarized) light. The simulation uses an input port placed in the air region, launching TM-polarized light ($Hz \neq 0$; $Hx = Hy = 0$) toward the sample. The model includes three layers: air, permalloy, and glass (air-permalloy-glass). Simulations were performed over a range of 400nm-700nm. The electromagnetic power loss (absorbed power per unit volume) was extracted at various positions spanning from the top to the bottom of the permalloy layer. Power losses get decreased in general as an increase in wavelength of the pulse. After building the same structure in COMSOL Heat Transfer Module, temperature profile during the pulse can be observed. During laser pulse the film becomes hot but gradually cools down.

The results show that power loss is highest at the top surface (air/film interface) and decreases toward the bottom (film/substrate interface). This follows the expected pattern from the skin effect. All power loss curves for different wavelengths intersect near 22 nm from the top. This crossover depth is close to the expected skin depth for permalloy. Below this depth, the loss becomes more uniform or slightly reverses. This may be due to reflection or interference at the film-glass boundary. The asymmetry in absorption suggests a vertical temperature gradient under laser light. This is important for generating ANE signals. In more complex structures, this gradient shape may change and cannot be found with simple calculations. That is why COMSOL simulations are very important

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