Vorobyev, Makin, and Guo Reply: In our original Letter [1], we demonstrated an enhanced emission efficiency of incandescent light sources through structuring the filaments with femtosecond laser pulses. The preceding Comment [2] focuses on one aspect in applying our technique in illuminating light bulbs [2]. First of all, we would like to point out that incandescent light sources have been used in various applications, mainly the following three categories: (i) broadband radiation sources used in spectroscopy, (ii) infrared lamps used as heat sources, and (iii) lighting bulbs for illumination. From the energy efficiency point of view, each category requires emission enhancement in different spectral regions. Although our study resulted from a certain wavelength due to the laser we used, one unique property of our technique, as we pointed out in the Letter, is allowing us to control the spectral range for optimal light absorption and emission [1,3,4]. Here, we will elaborate how our technique benefits each category of the applications.

Figure 1 shows spectral emittance reproduced from Fig. 3 in Ref. [1]. First of all, to enhance the energy efficiency of a broadband thermal radiation source, we would ideally want to enhance the emittance to unity throughout all wavelengths. In our study, we achieve an enhanced emittance well over 0.8 over the entire studied wavelength range by creating a broadband black metal, and this will clearly enhance the energy efficiency compared to an untreated tungsten lamp for a broadband radiation source.

Second, to enhance the energy efficiency for a heating source, we would need to produce a maximum amount of radiation in the infrared range but minimum at shorter wavelengths. An ideal spectral emittance for this type of lamps should have emittance of unity for $\lambda > 760$ nm but no enhancement for $\lambda < 760$ nm. We can see that the studied nanostructure-covered laser-induced periodic surface structures (NC LIPSSs) significantly enhance emittance in the infrared wavelength range we studied. However, the maximal emission of the NC LIPSSs produced in our study is at 800 nm because of the laser wavelength used in our experiments. As pointed out in our Letter [1], we can control the optimal emittance of NC LIPSSs to have maximum at longer wavelengths that will result in even a higher energy efficiency for heating.

Finally, we consider the category of illuminating light bulbs singled out in the Comment [2]. To enhance the energy efficiency for this category, the ideal case is to produce a maximum amount of radiation in the visible (380–750 nm) but minimum elsewhere. Again, as pointed out in our Letter, the emittance produced in our work is optimized around 800 nm due to the laser wavelength used. By using different wavelengths and by modifying our experimental conditions, we can shift the optimal emission peak to lower wavelengths. In fact, we have produced shorter-period NC LIPSSs by using 400 nm laser pulses that will have an optimal emittance within the visible range [3]. Furthermore, we have also created surface structures that have narrower spectral range for enhanced emittance [4]. One such example has been reported in a previous work of ours [4], where our measurements showed that the generated NC-LIPSSs significantly enhance absorption (emittance) in the visible without much modification in the infrared (Fig. 2 in Ref. [4]). In fact, our results there showed that the produced structures do not change absorptance at all for wavelengths above 1 μm [4], an ideal for illumination.

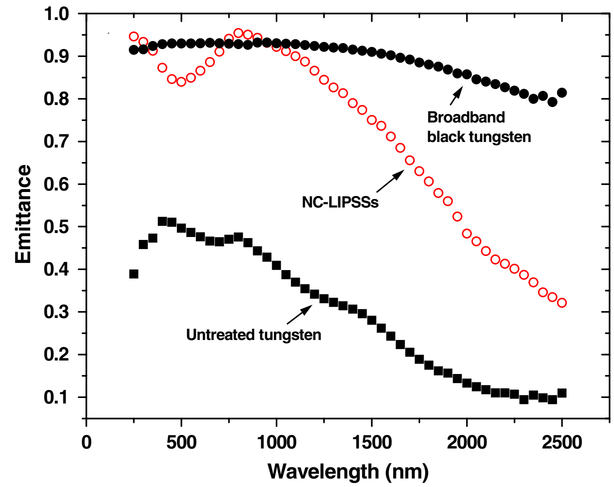

FIG. 1 (color online). Wavelength dependent emittance of untreated tungsten, tungsten covered with NC LIPSSs, and the black tungsten.

In summary, although our study focused on a specific wavelength due to the laser used, the spectral controllability of our technique allows us to enhance energy efficiency in various applications for incandescent light sources. The authors of the Comment [2] appear to miss this point.

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