Comment on "Brighter Light Sources from Black Metal: Significant Increase in Emission Efficiency of Incandescent Light Sources"

In a Letter published in 2009 [1], Vorobyev, Makin, and Guo reported that tungsten-based incandescent light sources became brighter after ~200 nm -wide nanotrenches were written on a tungsten surface by a femtosecond laser. Two interesting phenomena were observed. (i) The original Fig. 3 in [1] suggests that there is emission and reflectance enhancement within the laser irradiated area across the measured spectral range. Mishra, Zachau, and Levin pointed out that reflectance enhancement alone did not necessarily lead to increased efficacy. It was the relative emissivity differential between the visible region (approximately 400–750 nm) and the infrared region that determined system efficacy [2]. By taking the normalized emissivity ratio between the laser irradiated tungsten and the polished tungsten, one can notice in Fig. 1 that there is a cutoff wavelength around 400 nm that separates two regions. Below 400 nm, there is an emission enhancement (ratio >1). Immediately above 400 nm, there is suppression in emission (ratio <1). This relative emissivity modulation is relatively shallow but still noticeable. (ii) Light emitted from the laser irradiated surface was partially polarized.

The authors attributed these phenomena to free space coupling of surface plasmons. In my opinion, this is a microcavity effect, as opposed to a surface plasmon effect. Each nanotrench forms a resonant microcavity along the trench width. In the emitting spectrum, any mode with a wavelength of greater than 2 times the trench width in this direction is suppressed by these microcavities. Since the width of the trenches is ~200 nm, the cutoff wavelength is ~400 nm, which agrees with what is observed in Fig. 1. Some of the energy originally in these suppressed modes is shifted into the modes with shorter wavelengths, leading to an emission boost below 400 nm. The mode enhancement or suppression does not happen in the direction along the trench, resulting in partially polarized light emission.

The modulation depth in Fig. 1 is very shallow, because there is only one-dimensional confinement. In addition, the nanotrenches are actually optimized to enhance emission below 400 nm, as opposed to the visible range. Two-dimensional microcavities, such as circular holes, can offer much better emissivity enhancement. By setting the cutoff wavelength to ~750 nm (hole diameter ~375 nm) in a hole-based filament, one can engineer emission enhancement in the visible range. In this case, the emitted light will be unpolarized due to the rotational symmetry. In both cases, mode suppression happens only to the machined surface area. Since it is impossible to engineer a 100% fill factor for trenches or holes, the statement of reaching 100% efficiency has no foundation.

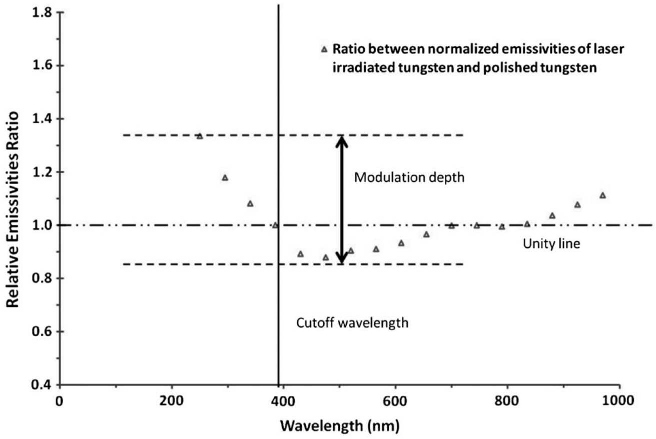

FIG. 1. Relative emissivity ratio as a function of wavelength. Data were obtained by taking the ratio between relative emissivities of nanostructure covered laser-induced periodic surface structures (laser irradiated tungsten) and polished tungsten (unirradiated tungsten) in the original Fig. 1 of Ref. [2].

On a separate but relevant topic, Vorobyev, Makin, and Guo believed that the periodic nanotrenches in [1] were produced by the interference between an incident laser light and the excited surface plasmons. In fact, this phenomenon was previously observed and reported by Siegman and Fauchet in 1986, who attributed these nanostructures to the interference between the incident beam and scattered beam from the surface being machined [3]. The existence of periodic nanotrenches does not necessarily suggest that there is a surface plasmon effect.

In conclusion, the phenomena reported in [1] are microcavity effects, as opposed to surface plasmon effects claimed by Vorobyev, Makin, and Guo. Carefully designed microcavities can be used to produce a cutoff in the emission spectrum. However, due to the fill factor limitation, the efficiency can never reach 100%.

Ming Li
Professional Lighting-Solid State Lighting R&D
OSRAM SYLVANIA Inc.
Danvers, Massachusetts 01923, USA

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