An IR emitter patterned at the nanoscale

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Spatial and spectral control of emissivity up to the diffraction limit with an inhomogeneous metasurface is experimentally demonstrated.

A blackbody is an ideal object that absorbs all incident radiation. According to Planck’s law, a blackbody is also a thermal source that emits light with a spectrum that can be determined from its temperature alone. This light emission is wideband, omnidirectional, and the wavelength of the maximum emission only depends on the temperature (as stated by Wien’s law). An interesting problem, however, is the possibility of making this emission tunable (i.e., so that it occurs over a specific spectral or spatial band). Indeed, the idea of controlling thermal emission has been a major topic of interest for many applications (e.g., gas sensing and thermophotovoltaics). One way to shape thermal emission is to use metasurfaces (thin materials structured with subwavelength patterns). It has been proven that these materials can be used to artificially tailor an electromagnetic response to achieve unprecedented light properties. For instance, metasurfaces that exhibit directional or monochromatic thermal emission (i.e., a groundbreaking feat, compared with blackbody emission) have been previously demonstrated. In addition, metal-insulator-metal (MIM) resonators are a compelling type of metasurface that are known for their total absorption properties. This makes them—according to Kirchhoff’s law—great candidates for efficient quasi-monochromatic IR emitters. In general, MIM metasurface designs are based on the periodic repetition of a building block. This repeating block—an antenna—consists of a rectangular metallic patch (with length, $L$, and width, $W$) deposited on a continuous insulator layer, which covers a continuous and optically opaque metallic layer. The antenna acts as a Fabry-Perot resonator for the horizontal mode propagating in the cavity that is formed below the metallic patch. Such metasurfaces also exhibit total absorption for transverse-magnetic polarized incident light at the resonance wavelength ($\lambda_r$). According to Kirchhoff’s law, the emissivity of a material at equilibrium is equal to its absorptivity. This means that a heated MIM metasurface emits light with the same properties as the absorption, and that it exhibits monochromatic (and nearly perfect) emissivity at $\lambda_r$. However, because of the periodicity of the pattern, the spatial modulation of the emissivity up to the wavelength scale cannot be achieved.

Figure 1. (a) Visible light picture of the inhomogeneous metasurface sample that consists of non-periodically arranged building blocks (a ladybug is shown as a size reference). The scanning electron microscope (SEM) image shows nine juxtaposed building blocks of the metasurface that contain a combination of metal-insulator-metal patches (antennas). (b) The emissivity spectra from each cell of the metasurface shown in (a). Spectra are given for both polarizations, i.e., horizontal (pink) and vertical (blue).

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In our work, we have thus designed an inhomogeneous metasurface, with building blocks that are not periodically arranged, so that we can enable encoding of far-field multispectral and polarized images. In our metasurface, we use MIM resonators to realize emissivity control up to the diffraction limit. The inhomogeneous metasurface consists of non-periodic micrometric emitters, each of which is composed of several subwavelength antennas that control the emission properties (i.e., wavelength, polarization, and intensity).

We have demonstrated our approach by encoding images on a $1.2 \times 0.8\text{cm}$ area, as illustrated in Figure 1(a). Each building block on the sample is a $2 \times 2\mu\text{m}$ square comprising a combination of antennas. The length of these antennas determines the emission wavelength, and their orientation sets the polarization. For example, the scanning electron microscope image in Figure 1(a) shows nine of the metasurface’s $2 \times 2\mu\text{m}$ building blocks (each with its own combination of MIM patches). The theoretical emissivity spectra from each of the nine building blocks are shown for both polarizations (i.e., horizontal and vertical) in Figure 1(b).

We have thus shown that the emissivity of our metasurface is encoded at the wavelength scale.

We have also developed a dedicated experimental setup so that we can characterize our metasurface. In this setup, we use a thermoelectric Peltier device to heat the sample to 373K and inject the emission from the metasurface (in the 3–5\text{$\mu$m} range) into a Fourier transform IR spectrometer (a Brucker VERTEX 70v). We then use a high-resolution IR camera—a mercury cadmium telluride Scorpio camera that has a $640 \times 512$ array of $15\mu$m pixels—and a $50\text{mm}$ focal length lens to image the emission. We have also added a polarizer to the setup so that we can select the correct polarization state of the light. The spectrometer provides spectral information (e.g., emissivity spectra) and the camera provides spatial information (i.e., from the IR images of the sample). This combination means we can couple the two sets of information.

Normalized IR images of our metasurface sample, which we obtained with our experimental setup, are shown in Figure 2. For one of the polarization states—see Figure 2(b)—we encoded an image of the French playwright Molière. In the encoded image each level of brightness corresponds to one antenna with a particular length. We thus converted the original image onto a 12-level grayscale, where each value is encoded with a specific length of antenna (the longer the antenna, the brighter the emission on the sample). For the cross-polarization, we encoded a set of letters. Each letter emits at a wavelength between 3 and 5\text{$\mu$m}, which corresponds to a given antenna length. To obtain IR images of each letter, we added filters to our experimental setup. The three letters (N, A, and O), emitting at wavelengths of 4.22, 4.73, and 5.24\text{$\mu$m}, respectively, are shown in Figure 2(c).

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In summary, we have developed an inhomogeneous meta-
surface with which we can achieve spatial modulation of emis-
sivity at the wavelength scale. Each building block of the
metasurface is an independent subwavelength emitter, on which
spectral information can be encoded. This opens up many po-
tential applications for our metasurface, e.g., for anti-counterfeit
devices (because of their high level of information encryption).
Another practical use of the metasurface is for biochemical sens-
ing, where the spatial juxtaposition of the emitters with partic-
ular spectra can be used to improve the specificity and versa-
tility of detection. In our future work we will seek to indepen-
dently control each of these subwavelength emitters to achieve
dynamic light emission.

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