Intaglio and Bas-Relief Metamaterials: Controlling the Colour of Metals

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Abstract: We demonstrate two new families of metamaterial: indented (intaglio) and raised (bas-relief) sub-wavelength periodic patterns - the manufacturing of which on a metal surface provides a mechanism for controlling the colour of the metal.

To the human eye the vast majority of pure, uncoated metals are 'colourless': they appear grey/white because they do not strongly absorb light at any visible wavelengths (gold and copper being obvious exceptions to this rule). Here, we report a form of structural colouring for pure metals which relies only on the formation of arrays of sub-wavelength elements inscribed into or raised above the surface to a depth/height of the order 100 nm.

In contrast to conventional metamaterials, these intaglio and bas-relief patterns (wherein a patterned 'layer' effectively sits on a 'substrate' of the same metal as shown in Fig. 1a) present a continuous metallic profile to incident light and constitute a new family of planar metamaterials. These surfaces can be engineered to selectively provide highly efficient resonant absorption, thereby dramatically changing the metal's reflection spectrum and perceived colour (Fig. 1b). By adjusting meta-molecule geometries one can achieve a wide palette of metallic colours. Fig. 1c illustrates how variations in simple, single ring intaglio designs on aluminium and gold can provide access to a significant proportion of colour space. The colours produced can, by design, be polarization-dependent or -independent and are relatively insensitive to viewing angle.

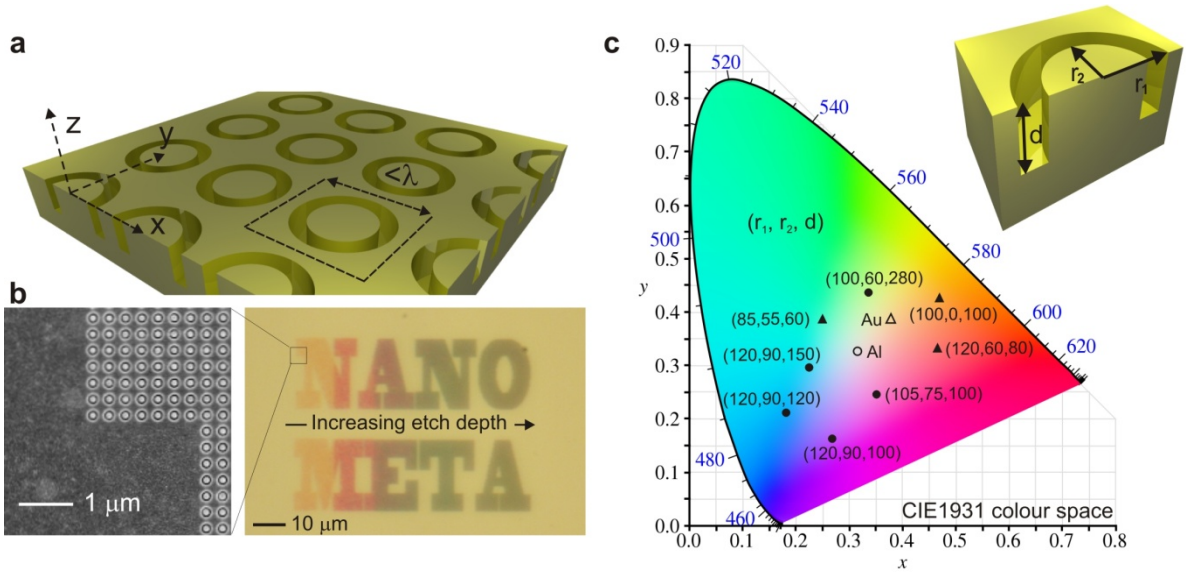

Fig. 1: *(a) Artistic impression of an intaglio metamaterial array; (b) The words 'NANO META' seen under an optical microscope [right] are formed from arrays of intaglio gold rings [left, under electron microscope] of varying depth; (c) CIE1931 chromaticity diagram overlaid with points corresponding to simulated reflected colours [under 6500 K blackbody illumination] of single-ring intaglio metamaterial designs [300 nm period] in aluminium [triangular symbols] and gold [circles], labelled according to their structural parameters. Points for the unstructured metals are indicated by open symbols.*

This novel approach to the structural colouring of pure metals offers great versatility and scalability for both aesthetic (e.g. jewellery design) and functional (e.g. banknote anti-forgery features) applications. We focus here on visible colours but the concept can of course be applied to the engineering of metallic spectral response in domains far beyond the visible range.