

Supporting Information

Brilliant colors originating from weak reflection of an ill-defined inverse opal structure and its application as a humidity sensor

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Fig. S1 Photographs of brilliantly colored regions (blue, green, and red) in Ethiopian and Australian picture and black opals, with corresponding color coordinates plotted on the Commission Internationale de l'Éclairage (CIE) chromaticity diagram.

Fig. S2 Reflectance spectra from various opals. Red, green, and blue regions of Ethiopian opal; blue and green regions of picture opal; and blue, green, and orange regions of black opal.

Fig. S3 Cross-sectional SEM images of Ethiopian opal after sequential etching treatments with hydrofluoric acid (HF).

Fig. S4 XRD patterns of Ethiopian opal, black opal, and a cristobalite reference.

Fig. S5 A high-angle annular dark-field (HAADF) image with TEM-EDS elemental mapping images for an FIB-cut sample of Ethiopian opal.

Fig. S6 Schematic illustrations of the experimental setup for reflectance spectra and a typical reflectance spectrum of the reference light irradiated on a white polytetrafluoroethylene (PTFE) plate.

Fig. S7 Photographs showing the positions for transmission spectra measurements of Ethiopian and black opals.

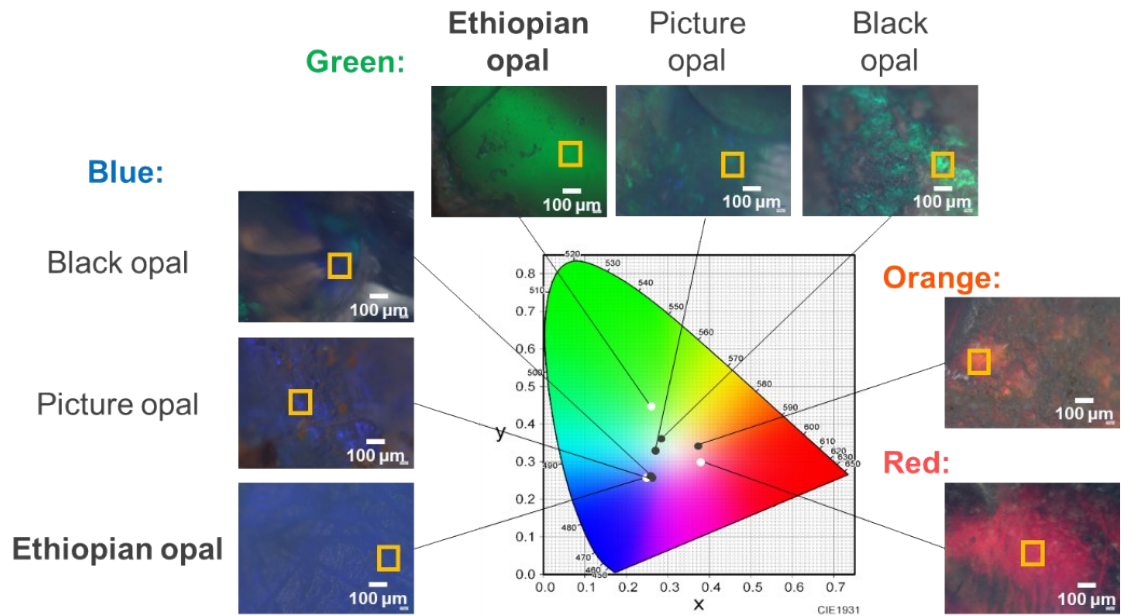


Fig. S1 Photographs of brilliantly colored regions (blue, green, orange and red) in Ethiopian, picture, and black opals, with corresponding color coordinates plotted on the Commission Internationale de l'Éclairage (CIE) chromaticity diagram. The central region and edges of the diagram indicate low and high color saturations, respectively. The structural colors were evaluated quantitatively from photographs using an image analysis software (ImageJ Fiji). The values of x , y , and z ($x + y + z = 1$) were calculated from the three primary colors.

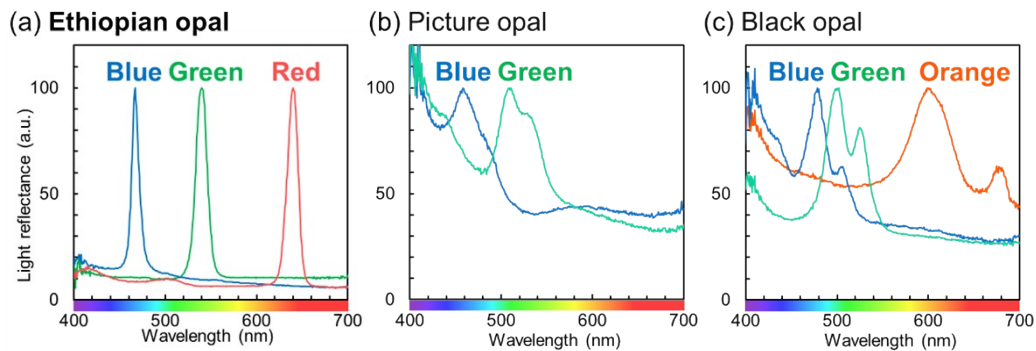


Fig. S2 Reflectance spectra from various opals. (a) Red, green, and blue parts of Ethiopian opal; (b) blue and green parts of picture opal; and (c) blue, green, and orange parts of black opal. Reflectance spectra were measured with the experimental setup shown in Fig. S6 in the SI. Light was incident vertically from the light source ($\theta = 0^\circ$).

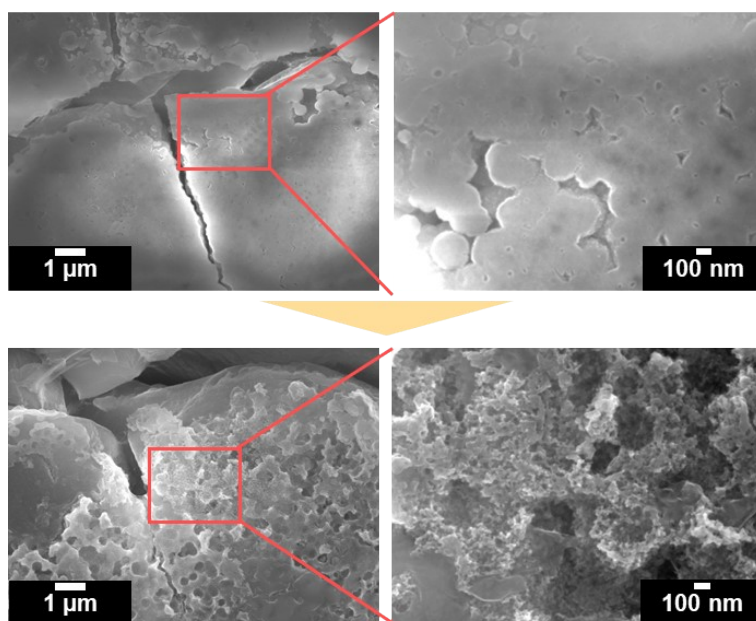


Fig. S3 Cross-sectional SEM images of Ethiopian opal: (a) after the etching treatment with 1.0 vol% HF for 30 s, and (b) the same area after further etching with 0.1 vol% HF for 5 min.

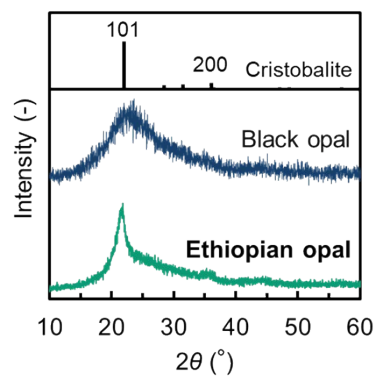


Fig. S4 XRD patterns of Ethiopian opal, black opal, and a cristobalite reference.

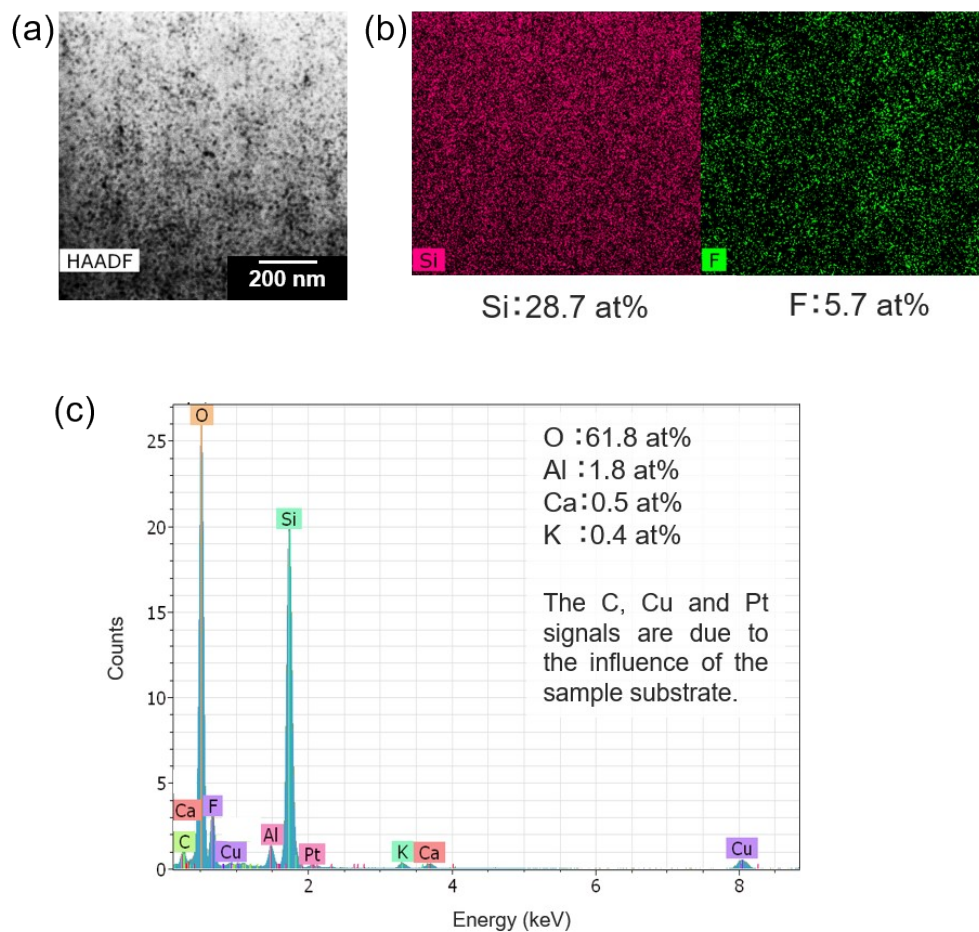


Fig. S5 A high-angle annular dark-field (HAADF) image with elemental mapping images for an FIB-cut sample of Ethiopian opal. (a) A HAADF image, (b) the elemental maps of silicon and fluorine, and (c) the EDS spectrum.

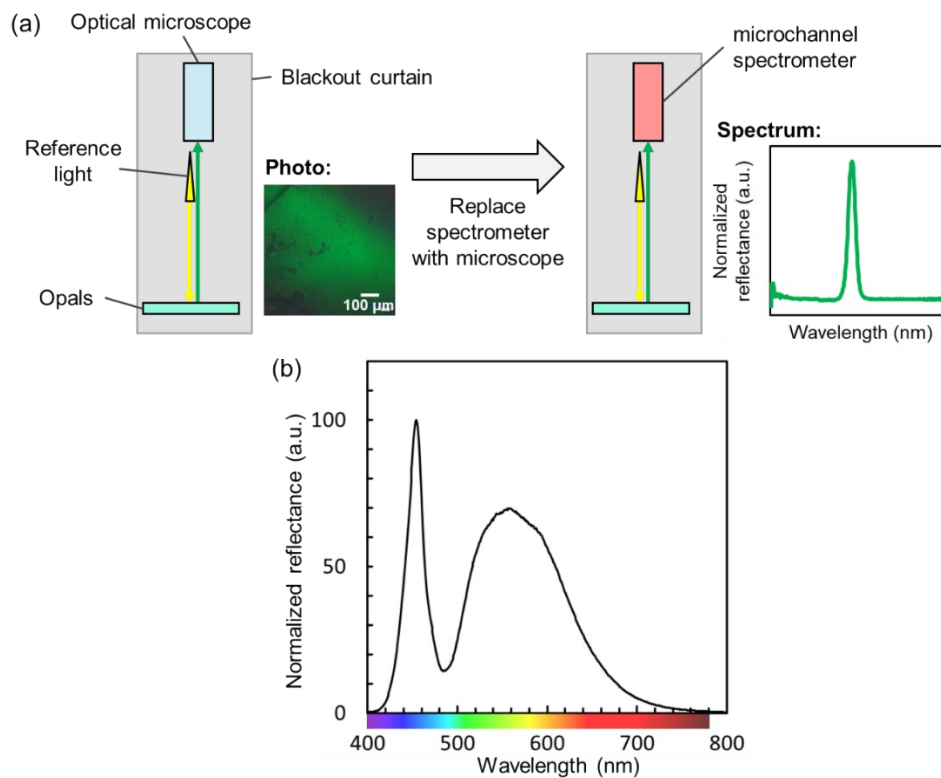


Fig. S6 (a) Schematic illustrations of the experimental setup for reflectance spectra. (b) A typical reflectance spectrum of the reference light irradiated on a white polytetrafluoroethylene plate. Light was incident vertically from the light source ($\theta = 0^\circ$).

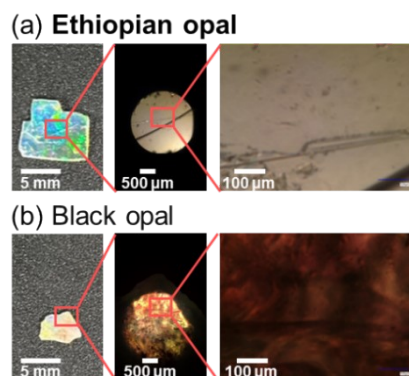


Fig. S7 Photographs showing the positions for transmission spectra measurements of (a) Ethiopian opal and (b) black opal. For both samples, the incident light was apertured using a pinhole 2 mm in diameter.