Fig. 10. The RGB colors calculated from the reflectance spectra for (a) $\phi = 0^\circ$ and (b) $\phi = 30^\circ$.

Fig. 11. The RGB colors reproduced by the multilayer model for (a) $\phi = 0^\circ$ and (b) $\phi = 30^\circ$.

system are expressed as follows:

$$X = \int_{380\text{nm}}^{780\text{nm}} R_\text{f}(\lambda)\bar{x}(\lambda)d\lambda \quad (6)$$

$$Y = \int_{380\text{nm}}^{780\text{nm}} R_\text{f}(\lambda)\bar{y}(\lambda)d\lambda \quad (7)$$

$$Z = \int_{380\text{nm}}^{780\text{nm}} R_\text{f}(\lambda)\bar{z}(\lambda)d\lambda. \quad (8)$$

In the present paper, CIE (1931) of 2-deg color matching functions in the CVRL Color & Vision database was employed as the three color matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ (The Colour & Vision Research Laboratory, 1995).

Next, X, Y and Z in the XYZ color coordinate system are converted into R, G and B in the RGB color coordinate system by means of the following formulae:

$$R = (3.5064X - 1.7400Y - 0.5441Z)/(X + Y + Z) \quad (9)$$

$$G = (-1.0690X + 1.9777Y + 0.0352Z)/(X + Y + Z) \quad (10)$$

$$B = (0.0563X + 0.1970Y + 1.0511Z)/(X + Y + Z). \quad (11)$$

Since the brightness of a monitoring screen is proportional to the about 2.2 to 2.4th power of a RGB value rather than proportional to a RGB value, the gamma correction for this (R, G, B) is performed. Here, the rectified value is defined by $(R', G', B') = (R^{1/2.2}, G^{1/2.2}, B^{1/2.2})$ (Fumoto, 1999). By using the intrinsic function, RGBColor, of Mathematica (Wolfram Research Inc., 1988), we can specify a color in terms of (R', G', B').

Actual calculations give $(X, Y, Z) = (8.65713, 13.3179, 0.8117)$ for the incident angles $\phi = 0^\circ$, and $(X, Y, Z) = (1.02966, 2.28491, 4.39062)$ for $\phi = 30^\circ$. The values of the RGB tristimulus values are, then, given as $(R, G, B) = (-0.357461, 0.463678, 0.548049)$ and $(R, G, B) = (0.29581, 0.751004, -0.0563071)$, respectively. Although each component of RGB color coordinates is originally defined as positive, one or two (never three) of the R, G, B coordinates often can turn out negative like this, which is the reason why the XYZ color coordinate system is introduced. This means that the color lies outside the "gamut" of colors that the monitor can reproduce. The out-of-gamut colors are fixed according to the standard way to add white—equal parts of R, G, and B—just enough to make all components positive, so bringing the color to the border of the gamut (Hamilton, 1999). That is, add $-\min(R, G, B, 0)$ to each of R, G, and B. Thus, we obtain $(R', G', B') = (0, 0.91432, 0.955886)$ for the incident angles $\phi = 0^\circ$ and $(R', G', B') = (0.622227, 0.907289, 0)$ for $\phi = 30^\circ$. By substituting these values into the function RGBColor of Mathematica, the RGB colors for the incident angles $\phi = 0^\circ$ and $\phi = 30^\circ$ are obtained, and shown in Figs. 10(a) and (b), respectively.

In the case of the incident angle $\phi = 30^\circ$, the structural color of light blue has appeared, which is very similar to one seen in Fig. 2(a).

Performing the same calculation for the TM mode of the multilayer model, we obtain values of (R', G', B') for the incident angle $\phi = 0^\circ$ and for $\phi = 30^\circ$ as $(0.84238, 0.663262, 0.310623)$ and $(0.390027, 0.837913, 0.35026)$, respectively. The colors reproduced in terms of these are shown in Figs. 11(a) and (b), respectively. We see that the reflected light never assumes a color close to a light blue in the multilayer model, whereas the log-pile model can reproduce the structured color.

6. Conclusions

Optical property of the log-pile structure of fibers as a model of the epidermis of an earthworm has been studied by means of the numerical method for photonic crystals. The reflection spectra for several incident angles have been