CLAIMS

1. A paint thickness measuring device, comprising:

a first continuous-wave (cw) laser;

a second continuous-wave laser;

a photomixer comprising:

an optical coupler configured to mix laser lights emitted by the first and second continuous-wave lasers and generate a terahertz (THz) wave,

a photomixer emitter configured to emit the terahertz wave, and

a photomixer receiver configured to detect the terahertz wave reflected off a painted surface;

one or more computer processors; and

a non-transitory computer-readable memory storing computer program instructions executable by the one or more computer processors to perform operations for paint thickness measurement, the operations comprising:

comparing the detected terahertz wave to simulation results;

identifying a minimum difference between the detected terahertz wave and the simulation results; and

determining a paint thickness of the painted surface from the simulation results with the minimum difference,

wherein the operations further comprise adjusting material parameters and a simulated paint thickness parameter of a simulation model to minimise a difference between the detected terahertz wave and the simulation model based on a particle swarm optimization (PSO) method comprising populating corners of a solution space of the simulation model with a plurality of particles, each particle representing a set of parameters comprising the material parameters and the simulated paint thickness parameter with respective assigned values thereto.

2. The paint thickness measuring device according to claim 1, further comprising a first Fresnel lens configured to focus the emitted terahertz wave from the photomixer emitter and a second Fresnel lens configured to refocus the terahertz wave reflected off the painted surface, each of the first and second Fresnel lenses having a diffractive optical element (DOE).

3. The paint thickness measuring device according to claim 2, wherein each of the first and second Fresnel lenses has a refractive index of about 3.44.

4. The paint thickness measuring device according to claim 2 or 3, wherein each of the first and second Fresnel lenses has a focal length of between about 10 centimetres (cm) and about 100 cm.

5. The paint thickness measuring device according to any one of claims 1 to 4, wherein the difference between the detected terahertz wave and the simulation model is represented by an error function defined by a cross-correlation of the detected terahertz wave and the simulation model as defined by Equations (1) and (2):

$$r_{in} \star r_{trial}(\tau) = \int_{-\infty}^{\infty} r_{in}(f)\, r_{trial}^{*}(f+\tau)df \qquad (1)$$

$$F\{r_{in} \star r_{trial}(\tau)\} = R_{in}(t) * R_{trial}(t) \qquad (2)$$

wherein

$r_{in}$ represents the detected terahertz wave,

$r_{trial}$ represents a simulated waveform,

$\tau$ represents a dummy variable for integration,

$f$ represents frequency,

$R_{in}$ represents a Fourier transform pair of $r_{in}$,

$R_{trial}$ represents a Fourier transform pair of $r_{trial}$,

$t$ represents a time delay, and

Equation (2) is a Fourier transform of Equation (1).

6. The paint thickness measuring device according to claim 5, wherein the operation of identifying the minimum difference between the detected terahertz wave and the simulation results further comprises:

mapping a magnitude of the detected terahertz wave into a time-domain using Equation (2) to obtain a magnitude component and an angle component.

7. The paint thickness measuring device according to claim 6, wherein the operation of identifying the minimum difference between the detected terahertz wave and the simulation results further comprises:

performing a filtering operation to remove the magnitude and angle components in the time-domain that are orders of magnitude lower than the magnitude and angle components at $t = 0$.

8. The paint thickness measuring device according to claim 7, wherein the operation of identifying the minimum difference between the detected terahertz wave and the simulation results further comprises:

reconstructing the detected terahertz wave with the filtered magnitude and angle components.

9. The paint thickness measuring device according to claim 8, wherein the operation of identifying the minimum difference between the detected terahertz wave and the simulation results further comprises:

computing cross-correlational errors between the input function and the trial function using Equations (3) and (4):

$$Error_{magn} = \left| \int_{-t}^{t} \left( \frac{|R_{in}(t)||R_{trial}(t)| - |R_{in}(t)|^2}{|R_{in}(t)|^2} - 1 \right) dt \right| \quad (3)$$

$$Error_{phase} = \left| \int_{-t}^{t} \left( \varphi_{trial}(t) - \varphi_{in}(t) \right) dt \right| \quad (4)$$

wherein

$Error_{magn}$ represents a magnitude of a cross-correlational error function,

$Error_{phase}$ represents a phase of the cross-correlational error function,

$\varphi_{trial}$ represents a phase of $R_{trial}$, and

$\varphi_{in}$ represents a phase of $R_{in}$.

10. A computer-implemented method for measuring paint thickness using the paint thickness measuring device of any one of the preceding claims, the method comprising executing on the one or more computer processors the steps of:

comparing the detected terahertz wave to simulation results;

identifying a minimum difference between the detected terahertz wave and the simulation results; and

determining a paint thickness of the painted surface from the simulation results with the minimum difference,

wherein the steps further comprises adjusting material parameters and a simulated paint thickness parameter of a simulation model to minimise a difference between the detected terahertz wave and the simulation model based on a particle swarm optimization (PSO) method comprising populating corners of a solution space of the simulation model with a plurality of particles, each particle representing a set of parameters comprising the material parameters and the simulated paint thickness parameter with respective assigned values thereto.

11. The computer-implemented method for measuring paint thickness according to claim 10, wherein the difference between the detected terahertz wave and the simulation model is represented by an error function defined by a cross-correlation of the detected terahertz wave and the simulation model as defined by Equations (1) and (2):

$$r_{in} \star r_{trial}(\tau) = \int_{-\infty}^{\infty} r_{in}(f)\, r_{trial}^{*}(f+\tau)df \qquad (1)$$

$$F\{r_{in} \star r_{trial}(\tau)\} = R_{in}(t) * R_{trial}(t) \qquad (2)$$

wherein

$r_{in}$ represents the detected terahertz wave,

$r_{trial}$ represents a simulated waveform,

$\tau$ represents a dummy variable for integration,

$f$ represents frequency,

$R_{in}$ represents a Fourier transform pair of $r_{in}$,

$R_{trial}$ represents a Fourier transform pair of $r_{trial}$,

$t$ represents a time delay, and

Equation (2) is a Fourier transform of Equation (1).

12. The computer-implemented method for measuring paint thickness according to claim 11, wherein the step of identifying the minimum difference between the detected terahertz wave and the simulation results further comprises:

mapping a magnitude of the detected terahertz wave into a time-domain using Equation (2) to obtain a magnitude component and an angle component.

13. The computer-implemented method for measuring paint thickness according to claim 12, wherein the step of identifying the minimum difference between the detected terahertz wave and the simulation results further comprises:

performing a filtering operation to remove the magnitude and angle components in the time-domain that are orders of magnitude lower than the magnitude and angle components at $t = 0$.

14. The computer-implemented method for measuring paint thickness according to claim 13, wherein the step of identifying the minimum difference between the detected terahertz wave and the simulation results further comprises:

reconstructing the detected terahertz wave with the filtered magnitude and angle components.

15. The computer-implemented method for measuring paint thickness according to claim 14, wherein the step of identifying the minimum difference between the detected terahertz wave and the simulation results further comprises:

computing cross-correlational errors between the input function and the trial function using Equations (3) and (4):

$$Error_{magn} = \left| \int_{-t}^{t} \left( \frac{|R_{in}(t)||R_{trial}(t)| - |R_{in}(t)|^2}{|R_{in}(t)|^2} - 1 \right) dt \right| \quad (3)$$

$$Error_{phase} = \left| \int_{-t}^{t} \left( \varphi_{trial}(t) - \varphi_{in}(t) \right) dt \right| \quad (4)$$

wherein

$Error_{magn}$ represents a magnitude of a cross-correlational error function,

$Error_{phase}$ represents a phase of the cross-correlational error function,

$\varphi_{trial}$ represents a phase of $R_{trial}$, and

$\varphi_{in}$ represents a phase of $R_{in}$.