problem of a deterioration in throughputs. Moreover, a way to address the above-described problem using the laser having the another wavelength as disclosed in Non-Patent Literature 1 is not unsuitable for practical applications because the number of process steps is increased by a process such as separation of the absorption layer.

Still further, the method using the blue semiconductor laser based on GaN in Patent Literature 7 is essentially the same as a melt process, and unsuitable for industrial applications in terms of extremely low output resulting from limitation to the use of the blue semiconductor laser based on GaN in the process.

[0008]

The present invention is directed to overcome the problems of the conventional techniques as described above, and provide a laser annealing apparatus and a laser annealing method with which a large-area semiconductor film can be evenly and uniformly crystallized through the use of a laser beam that is absorbed in the semiconductor film and composed so as to have an effective power density defined in this application in a specific range without requiring any complicated process.

MEANS FOR SOLVING BY THE INVENTION

[0009]

A~~Specifically, a~~ laser annealing apparatus according to a first aspect of the present invention irradiates an amorphous semiconductor film with a pulsed laser beam in a state of heating where the amorphous semiconductor film is not completely molten to perform crystallization of the amorphous semiconductor film. The laser annealing apparatus ~~according to a first invention~~ comprises a

pulsed laser oscillator that outputs a pulsed laser beam, and an optical transmission means that transmits the pulsed laser beam output from the pulsed laser oscillator to irradiate a semiconductor film with the pulsed laser beam, in which the pulsed laser beam is irradiated onto the semiconductor film

in a condition where the pulsed laser beam has an energy density of from 100 to 400 mJ/cm^2 and an effective power density calculated by the following formula falls within a range of from 2.7~~3~~ × 10^{12} to 1.5 × 10^{12} on~~at~~ an irradiation surface of the semiconductor film.

effective power density (J/(sec•cm^3)) = pulse energy density (J/cm^2) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)

[0010]

The laser annealing apparatus according to a second aspect of the present invention irradiates an amorphous semiconductor film with a pulsed laser beam in a state of heating where the amorphous semiconductor film is not completely molten to carry out crystallization of the amorphous semiconductor film. The laser annealing apparatus ~~according to a second invention~~ comprises a continuous laser oscillator that outputs a continuous laser beam, an optical transmission means that transmits the continuous laser beam output from the continuous laser oscillator and a pulsed laser beam split from the continuous laser beam to irradiate a semiconductor film with the pulsed laser beam, and a pulsed laser beam generating means that splits the continuous laser beam during the transmission into a pseudo pulsed shape to thereby generate a pulsed laser beam. In the laser annealing device, the pulsed laser beam is irradiated onto the semiconductor film in the condition where the effective power density calculated by the following formula falls within a range of from 2.7~~3~~ × 10^{12} to 1.5 × 10^{12} on~~at~~ the irradiation surface of the semiconductor film.

effective power density (J/(sec•cm^3)) = pulse energy density (J/cm^2) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)

[0011]

The laser annealing apparatus according to an embodiment~~of the present invention according to a third invention~~ further comprises, in the first or second invention, an energy adjusting means that adjusts an energy density of the pulsed laser beam. In the energy adjusting means, the energy density is defined in such a manner that the effective power density calculated by the

above-described formula falls within the range of from 3×10^{12} to 1.5×10^{12}.

[0012]

The laser annealing apparatus according to another embodiment ~~of the present invention according to a fourth invention~~ comprises, as the energy adjusting means in one of the above embodiments~~the third invention~~, an attenuator that attenuates the pulsed laser beam at a predetermined attenuation rate and an output adjusting means that adjusts an output of the laser oscillator. In the attenuator and the output adjusting means, the attenuation rate and the output are defined in such a manner that the effective power density calculated by the above-described formula falls within the range of from 2.7~~3~~ $\times 10^{12}$ to 1.5×10^{12}.

[0013]

The laser annealing apparatus according to another embodiment~~of the present invention according to a fifth invention~~ further comprises, in any one of the above embodiments~~first to fourth invention~~, a pulse width adjusting means that adjusts a pulse width of the pulsed laser beam. Further, the pulse width adjusting means adjusts the pulse width of the pulsed laser beam in such a manner that the effective power density calculated by the above formula falls within the range of from 2.7~~3~~ $\times 10^{12}$ to 1.5×10^{12}.

[0014]

The laser annealing apparatus according to one embodiment~~of the present invention according to a sixth invention~~ has characteristic features that the semiconductor film is a silicon semiconductor film, the energy density is from 100 to 500 mJ/cm^2, and the pulse width is from 50 to 500 nsec in any one of the above embodiments~~first to fifth invention~~.

[0015]

A laser annealing method according to a third aspect of the present invention irradiates an amorphous semiconductor film with a pulsed laser beam in a state of heating where the amorphous semiconductor film is not completely molten to perform crystallization of the semiconductor film. The method comprises the~~according to a seventh invention comprises, in a~~ laser

annealing method for irradiating a semiconductor film with a pulsed laser beam to perform laser annealing of the semiconductor film, setting a pulse energy density and a pulse width of the pulsed laser beam in such a manner that the pulsed laser beam has an energy density of from 100 to 400 mJ/cm^2 and an ~~the~~ effective power density calculated by the following formula ~~falls~~ within a range of from 2.7~~3~~ × 10^{12} to 1.5 × 10^{12} on an irradiated~~at the irradiation~~ surface, and irradiating the thus-set pulsed laser beam onto the semiconductor film with the pulsed laser beam having the defined pulse energy density and pulse width, the effective power density being calculated by a formula of:

effective power density (J/(sec•cm^3)) = pulse energy density (J/cm^2) / pulse width (sec) × absorption coefficient of semiconductor film (cm^{-1}) ••• (Formula)

[0016]

According to embodiments of the present invention, the pulsed laser beam is produced to satisfy an appropriate relationship among the energy density, the pulse width, and the absorption coefficient, and irradiated onto the semiconductor film, to thereby rapidly heat up the semiconductor film for application of heat at which the semiconductor film is not completely molten. In this way, it is possible to obtain uniform crystalswith small variability in grain size, with a technique different from conventional complete melt/recrystallization methods. Conventional melt crystallization methods or SPC (solid phase crystallization) by means of a heating furnace result in the presence of a wide range of variations in crystal grains.

Next, conditions defined in the present invention will be described below.

[0017]

Effective Power Density: within the range of from 3×10^{12} to 1.5×10^{12}