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Computational and experimental study of nanosecond laser ablation of crystalline silicon[☆]

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ABSTRACT

In this paper, a numerical model of nanosecond laser ablation of crystalline silicon has been established. Based on the highly nonlinear model of heat transfer and phase change in crystalline silicon after absorbing laser light, heat transfer equation is solved by using finite element method implemented in ANSYS. The simulation of ablation depth of crystalline silicon is obtained under different conditions of laser fluence and pulse overlap. Comparing with the ablation morphology obtained from SEM observations, the computational results and experimental data show good agreement.

1. Introduction

Laser ablation of crystalline silicon is a fundamental processing for laser-grooved solar cells. BP Solar Global had already achieved industrial production of laser grooved buried contact silicon solar cells by the technology of University of New South Wales (UNSW) [1]. Therefore, it is necessary to carry out theoretical investigation on laser ablation of crystalline silicon.

In this work, the focus is on computational and experimental study of nanosecond laser ablation of crystalline silicon by the construction of a numerical model. Based on the highly nonlinear model of heat transfer and phase change in crystalline silicon after absorbing laser light [2,3], heat transfer equation is solved by using finite element method implemented in ANSYS. The laser ablation depth and ablation morphology of crystalline silicon are obtained with different laser fluence and pulse overlap.

2. Model

Fig. 1 shows the schematic diagram of theoretical model. The laser light along z-axis heats locally the crystalline silicon on the platform, which could move along x-axis. Non-steady-state temperature distribution could be obtained by applying the heat transfer and phase change model of laser heating crystalline silicon [4,5]. Ignoring gas dynamic and fluid dynamic effects [6], the differential equation describing this process temperature T(y,z,t) is [7–9]:

$$c(T)\rho(T)\frac{\partial T(y,z,t)}{\partial t} = K(T)\left(\frac{\partial^2 T(y,z,t)}{\partial y^2}+\frac{\partial^2 T(y,z,t)}{\partial z^2}\right)+Q(T,y,z,t) \quad (1)$$

Here K is the thermal conductivity, c is the specific heat capacity, ρ is the material density and Q is the heat generation rate. The initial temperature without laser irradiating is environmental temperature:

$$T(y,z,t)|_{t=0} = T_{env} \quad (2)$$

The boundary conditions for the temperature are different between the heated top surface and the other surfaces. Because of the high heat flow gradients during laser heating crystalline silicon, no heat is lost from the irradiation side. Therefore, the Neumann boundary condition is used at the boundary where z = 0. However, the laser-affected depth is much smaller than the thickness of crystalline silicon. Consequently, the other surface is assumed to stay at environmental temperature according to the Dirichlet boundary condition, expressed as follows:

$$\frac{\partial T(y,z,t)}{\partial z}|_{z=0} = 0 \quad (3)$$

$$T(y,z,t)|_{z=\text{thickness of sample}} = T_{env} \quad (4)$$

According to the theory of heat transfer in solids, the analytical solution to Eq. (1) could been obtained when laser power density is not dependent upon time [10]. However, the energy distribution of pulsed laser usually is Gaussian shape. As wafers on the platform moved relatively to the laser beam, the absorbed heat of the area of crystalline silicon irradiation is always changing. Analytic solutions are no longer available for actual laser pulse shapes. In addition, laser pulses energy generally offers several times the amount of energy required to raise the unit mass from room temperature to the melting or evaporation temperature within a very short period. The considerably large heat flow gradients make the thermal properties of crystalline silicon temperature-dependent. Therefore, the finite

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