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ANNEALING OF ION-IMPLANTED SILICON BY AN INCOHERENT LIGHT PULSE--ETC(U)
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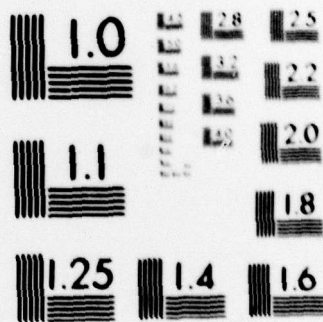
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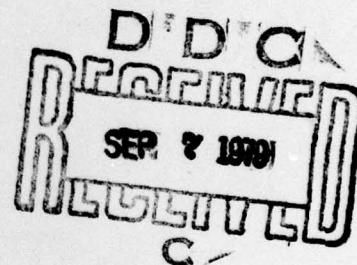
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**ANNEALING OF ION-IMPLANTED SILICON BY AN INCOHERENT
LIGHT PULSE**

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ELECTRONICS TECHNOLOGY & DEVICES LABORATORY

July 1979

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Annealing of ion-implanted silicon by an incoherent light pulse

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Annealing of boron-implanted silicon by a single 15- μ sec pulse from a flash lamp has been observed. The required energy density was 27 J/cm² incident on the silicon. Electrical activity of boron was comparable to that in thermally annealed samples.

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Laser annealing of ion-implanted semiconductors is currently of interest as an alternative to thermal annealing. In this letter we report the successful annealing of boron-implanted silicon by a single light pulse from a high-power flash lamp.

For purposes of experimental design, we assumed that for annealing the silicon surface must melt. On this basis we calculated the energy density required for annealing with various-length light pulses. We calculated the temperature evolution and profile of the silicon using a one-dimensional diffusion equation with the following boundary conditions: a rectangular incident light pulse which is absorbed exponentially versus depth, with no outward heat loss from the surface. The general solution (assuming no melting) is

$$T(x, t) = \int_0^t (F^+ + F^-) \frac{\lambda}{c\rho} I(t') dt',$$

$$F^\pm = \frac{1}{2} \exp(\pm \lambda x) \operatorname{erfc} \left(\frac{\lambda(a)^{1/2}}{2} \pm \frac{x}{(a)^{1/2}} \right) \exp \left(\frac{\lambda^2 a}{4} \right),$$

$$a = 4D(t - t'),$$

where λ is the linear absorption coefficient = 10⁴/cm, D is the diffusivity = 0.9 cm²/sec, c is the specific heat = 0.7 J/gC, ρ is the density = 2.33 g/cm³, and $I(t)$ is the power density absorbed by the silicon (assumed to be two-thirds of the incident power density). This equation was integrated numerically; typical results are shown in Fig. 1. The heat of fusion was accounted for by demanding that the calculated temperature rise above the melting point by a fusion temperature defined as T_f = heat of fusion/specific heat ~ 2200 °C.

Figure 2 shows the calculated incident energy density required to reach the melting temperature and to melt the surface for varying-duration rectangular incident light pulses. Experimental points where annealing has been reported are shown¹⁻⁴; also shown is a calculation of threshold for melting assuming a Gaussian incident pulse.⁵ Our calculation indicated that there is a region of pulse length and energy density that is accessible by a spark-discharge flash lamp operating in the micro-second range.

An available 18-kV capacitor bank of 60- μ F capacitance was used to power the flash lamp shown schemat-

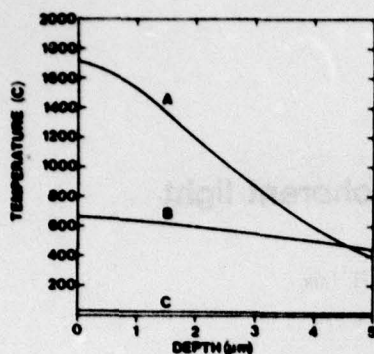


FIG. 1. Temperature profile in silicon at the end of a 1-J/cm² pulse of: A—10⁻⁷-sec, B—10⁻⁶-sec, C—10⁻⁵-sec duration.

ically in Fig. 3. To increase the light utilization, the tungsten electrodes were surrounded by a hemispherical aluminum mirror. The silicon samples were located within the stainless-steel enclosure of the flash lamp about 4 cm from the center of curvature in order to produce sufficiently uniform illumination of the 1-cm² surface. This location also reduced the effect of the acoustic shock wave which was also focused by the mirror and frequently destroyed our early samples.

Both argon and xenon were used as filling gases at pressures from 5 to 1500 Torr. In all cases, a strong light pulse of 15-μsec duration was obtained. The duration of the pulse is governed mainly by the self-inductance of the capacitor bank. An operating pressure

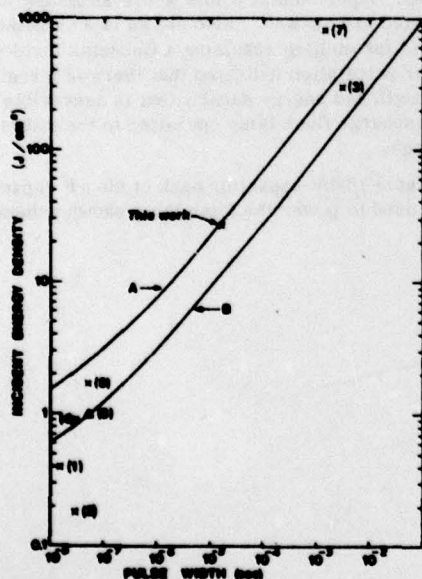


FIG. 2. Calculated energy density incident on the surface of a silicon slab versus pulse width. A—To produce complete melt at the surface, B—to heat the surface to the melting point. x refers to a previously observed laser annealing; Δ refers to a previous calculation of melting threshold. The parenthetical numbers indicate corresponding references.

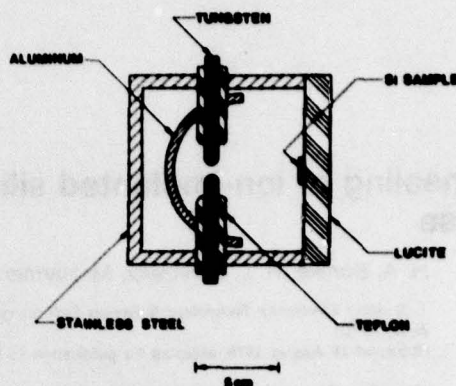


FIG. 3. Flash-lamp design.

of 30 Torr was selected. At this pressure the light output is not reduced significantly from that at high pressure, and the shock wave at the sample is still acceptably low. Figure 4 shows a pulse recording for argon at 30 Torr as measured by a photocell.

The samples used were polished wafers of 1 Ω cm (111) n-type silicon implanted with 10¹¹ boron/cm² at 50 keV. After exposure the samples were cleaned in HF and hot chromic acid and rinsed in deionized water to remove any possible surface deposits. They were then examined by both two-point-probe surface spreading resistance measurements and four-point-probe sheet resistance measurements. Before exposure the spreading resistance was 5500 Ω; after flash annealing it dropped to as low as 125 Ω. For comparison, a thermally annealed sample (900 °C, 60 min) showed a spreading resistance of 160 Ω. Sheet resistances for the flash-annealed samples were between 160 and 220 Ω/□; for the thermally annealed sample it was 116 Ω/□. The reduction of both spreading and sheet resistances after flash exposure to values comparable to thermally annealed samples indicated that annealing (i. e., increased electrical activity of the boron and decreased crystal damage) has been achieved.

The mirror was exposed to hot gases and evaporated material inside the container; after many flashes its surface roughened and blackened and had to be re-polished. In no case was annealing seen with the mirror

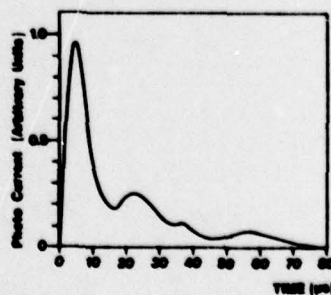


FIG. 4. Oscillograph of typical light pulse under operating conditions of 18-kV 30 Torr argon.

degraded, indicating that efficient light focus was a requirement for annealing.

The energy density required for annealing was measured by placing a total-absorption calorimeter in the sample holder. Under conditions which gave good annealing the incident energy density was 27 J/cm^2 . This value is approximately the calculated value for surface melting. However, we have no direct evidence that the surface actually melted.

We thank S. Marshall for his valuable comments and A. Mark for providing us with the implanted samples.

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