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TITLE: DESIGN AND FABRICATION OF A HIGH-DAMAGE THRESHOLD INFRARED SMARTT INTERFEROMETER

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Design and fabrication of a high-damage threshold infrared Smartt interferometer*

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It has been shown that a Smartt interfercmeter may be used as a very precise alignment tool for infrared lasers.(1) This interferometer may also be used effectively to investigate the phase front of a laser pulse. To use this tool for applications to high-power, fast-pulse laser systems such as Helios and Antares; however, it has been necessary to fabricate a structure with the unique optical characteristics of the Smartt interferometer combined with a very high optical-damage threshold. We have been successful in this effort by utilizing the high technology, process control, and unique properties of semiconductor-grade, single-crystal Si.

The basic requirements for the infrared Smartt interferometer are that it be optically thin (~10 μm), have a transmittance of $\lesssim$5%, and be resistant to damage by high-intensity, pulsed-laser illumination. Because of its optical properties and because of the high technology associated with it, Si is a suitable material for this application. Si has an optical damage threshold of 0.95 ± 0.15 J/cm^2(ref. 2) for nanosecond CO_2 laser pulses. Also, large-area (~1 cm^2), self-supporting, uniformly thick films of Si as thin as 0.7 μm(ref. 3) can be fabricated. Finally, by selective doping, the absorption coefficient of Si for 10.6-μm light can be controlled between 1 and >10^4 cm^{-1}.(ref. 4)

In this work we obtained films of Si 13 μm in thickness by the method of Meek et al. One and one-half inch diameter, single-crystal Si wafers obtained from Semimetals, Inc. with 13-μm-thick, 6-Ω-cm, n-type epitaxial layers and 0.01-Ω-cm, n-type substrates were used. The substrate was removed from an ~1-cm^2 area in the center of each wafer by a selective electrochemical etch. The quality of the films produced in this manner is determined solely by the quality of the Si epilayer.(5) For ~10-μm thick films we achieved thickness uniformity to ±2%.

The intrinsic absorption coefficient for 10.6-μm light in Si is ~1 cm^{-1}.(ref. 4) By doping the crystal and thus introducing free carriers, this absorption can be increased. Absorption due to free carriers in Si may be calculated using the following equation(4):

$$\lambda_{fc} = \frac{\lambda^2 q^3}{4\pi^2 c^3 n^* \epsilon_o} \left| \frac{n}{M_n^2 \mu_n} + \frac{p}{M_p^2 \mu_p} \right| \qquad (1)$$

where:

λ = wavelength of the light,

n^* = index of refraction,

q = electronic charge,

c = speed of light,

ϵ_o = permittivity of free space,

n and p = concentrations of free electrons and holes,

M_n and M_p = effective masses of free electrons and holes, and

μ_n and μ_p = mobility of free electrons and free holes.

For normal incidence, the intrinsic reflectivity of Si is 30%. If we increase the absorption coefficient of Si to 10^4 cm^{-1} at 10.6 μm by selective doping, this reflectivity is unaffected. Further increases in absorption will, however, increase the reflectivity. If we introduce a concentration of ~3 x 10^{19} cm^{-3} electrons into a Si crystal by doping with P, we calculate, using Eq.(1), an absorption coefficient at 10.6 μm of ~10^4 cm^{-1}. If the doped layer is 3 μm thick, then we expect the transmission of the crystal at 10.6 μm to be ~3.5% including reflection losses). In this work we achieved an absorbing layer at the surface of a Si film of approximately this nature. Using a spin-on P-doped, oxide-diffusion source,

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we performed a 19-min predeposition diffusion followed by an 18-h drive-in diffusion both at 1100°C in an N_2 atmosphere.(6) The transmission at 10.6 μm of this layer was measured to be 1.9 ± 0.1%. One can control the final transmittance achieved by varying the predeposition time or temperature. We chose the long drive-in at high temperature in order to produce a doping concentration as uniform as possible. Radial nonuniformities in doping concentration would most severely affect the uniformity of the phase change of light passing through the interferometer. Any such nonuniformity in the phase change would of course degrade the operation of the interferometer.

The n^+ substrate was removed from the Si wafer by electrochemical etch after the P diffusion. The experimental set-up is shown in Fig. 1. After the substrate was removed, a 50-μm-diam hole was introduced into the epilayer by high-energy pulsed laser illumination. Finally, the wafers were mounted for positioning in optical systems. The entire sequence for the Si Smartt interferometer fabrication is shown in Fig. 2.

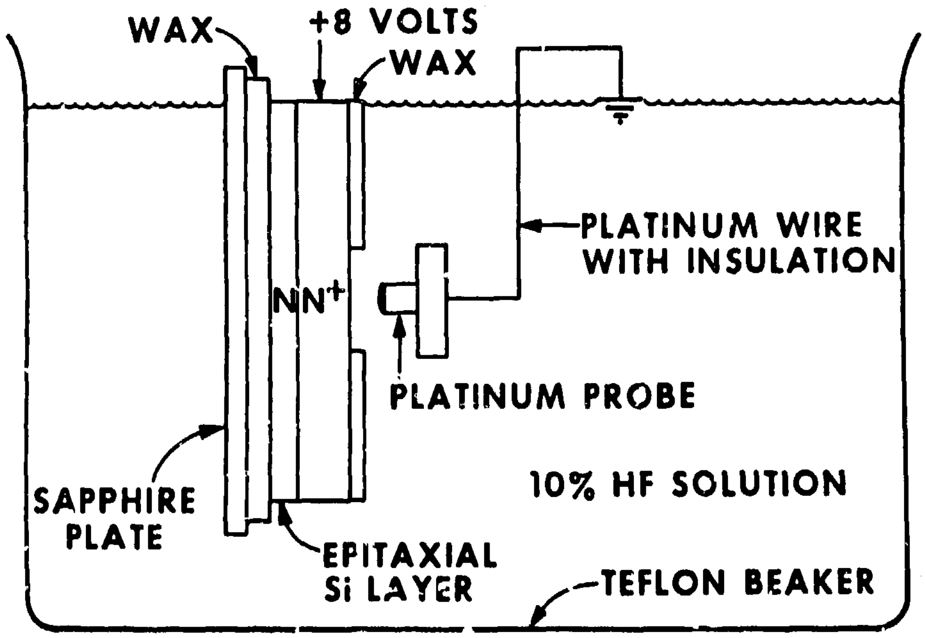

Fig. 1. Electro-etch set-up for removing n^+ substrate from n-on-n^+ Si wafer.

The interferometer described here has been used successfully for both (a) alignment of CO_2 lasers and (b) phase-front diagnostics of CO_2 laser beams. Further work is being done to increase the range of application for this class of devices.

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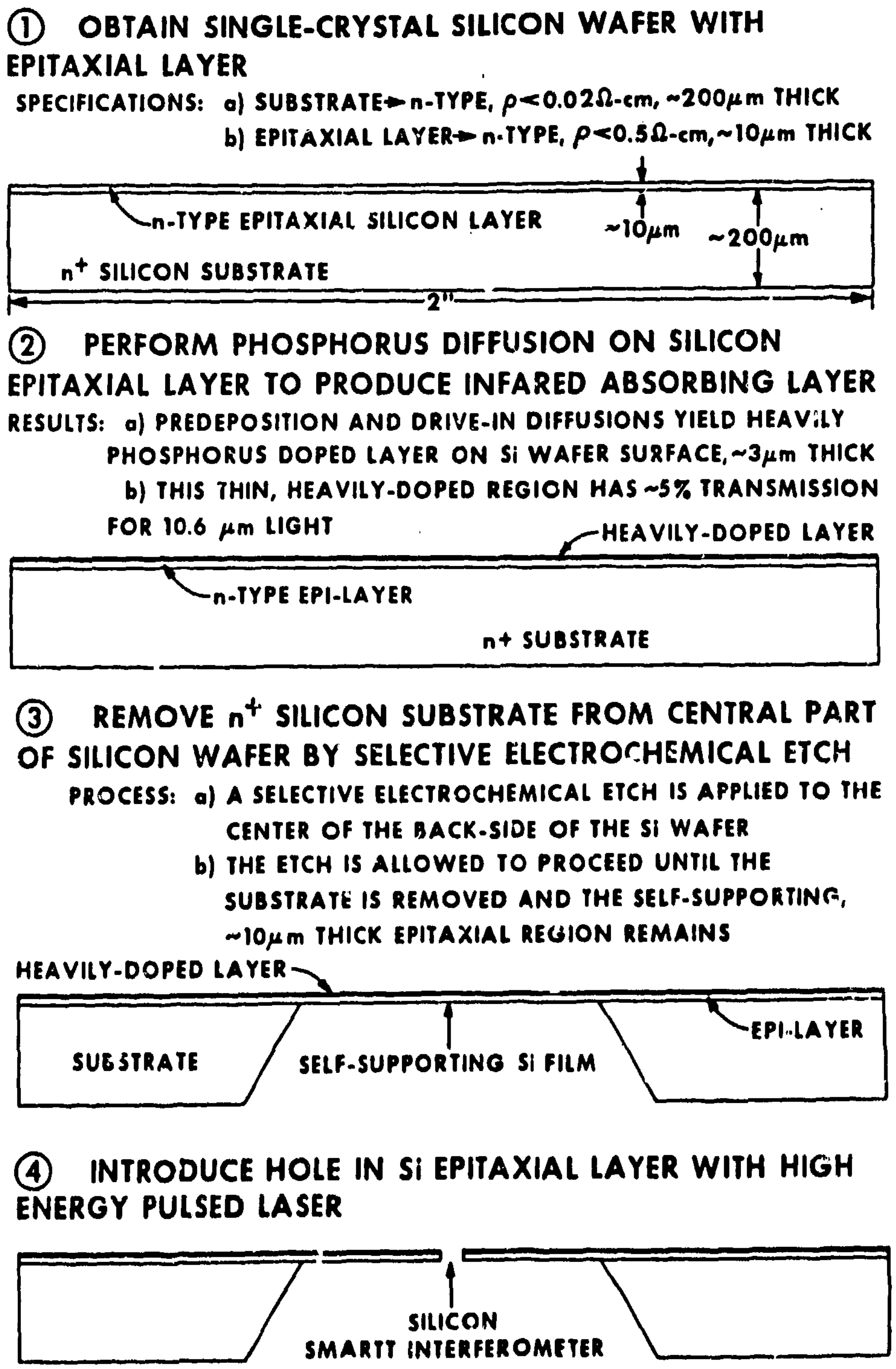

Fig. 2. Sequence of steps in the fabrication of a Si infrared Smartt interferometer.