# DETECTION OF SHUNT RESISTANCE IN SILICON SOLAR CELLS USING LIQUID CRYSTALS

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ABSTRACT: The location of shunt defects is an important tool in characterising solar cells. In this paper, we present a new method for shunt location in solar cells using Nematic Liquid Crystal (NLC) films. Advantages of the method include high spatial resolution, speed of measurement and experimental simplicity. A film of NLCs has the property of elliptically polarising normally incident plane polarised light when the film temperature is below the NLC-isotropic phase transition temperature. Consequently, when a NLC coated wafer is illuminated with plane polarised light and viewed through a crossed plane polarising filter, regions at a temperature above the transition temperature appear black. Temperature differences as low as 0.1°C can be detected using the NLC method. Since the images are viewed under a microscope, coarse shunt location can be quickly carried out at low magnification, followed by precise location at high magnification. The viability of the technique is demonstrated using devices which had deliberatively introduced shunt defects at known locations, as well as with a buried contact solar cell which had a low lumped shunt resistance. Results show that the technique is able to detect shunts with a spatial resolution of several microns.
Keywords: Shunt Location - 1: Liquid Crystal - 2: Buried Contact - 3

## 1. INTRODUCTION

The lumped shunt resistance routinely measured for solar cells usually corresponds to severe localised defects. To determine the physical causes of these defects, they must first be located.

Infra-red thermal imaging may be used since in a reverse biased solar cell a localised shunt is responsible for locally increased current density and therefore local heating. The primary problem with this method is the extremely expensive nature of the thermal imaging camera. Ultra high sensitivity(10 µK resolution) thermal imaging of solar cells, under forward and reverse bias, has been achieved using a scanning contact probe approach [1].

Nematic Liquid Crystal microthermography is an alternative method to expensive and specialised thermal imaging systems. This non-destructive technique is already used for detecting hot spots in integrated circuits and other semiconductor devices [2][3]. The technique is cheap and simple but allows fast and precise shunt location. Since examination of the sample is done via a microscope, the technique allows easy analysis of both large areas as well as pinpointing the exact location of the shunt.

## 2. LIQUID CRYSTALS

The liquid crystalline state is intermediate between that of a crystalline solid and an isotropic liquid. The state possess the mechanical properties of liquids (fluidity, surface tension) and the optical properties of crystalline solids (i.e., anisotropy, birefringence [4]). Liquid Crystal (LC) ordering properties (and therefore optical properties) can be controlled by electric or magnetic fields, hence their common application in displays.

Thermotropic LCs (thermally activated phase transition) can be divided into 3 classes based on their optical properties. These are known as Smectic (structurally most like a solid), Nematic and Cholesteric [5]. The latter two both belong to the more liquid-like structural classification, also called (unfortunately) "Nematic". In this paper, "Nematic" refers to the optical class. For a given class of LC, various forms (known as textures) exist in which the orientation of the LC molecules with respect to the surface is different. The planar texture (long axis of molecules parallel to the surface) is of most interest.

Cholesteric LCs in the planar texture are birefringent, optically active and circularly dichroic. Nematic LCs are birefringent only. The cholesteric type are widely used in non-destructive thermal testing. This is because they can be formulated so that when white light is incident on them, the colour of the reflection is temperature dependent. This type is not suitable for shunt location, because the sensitivity to the small temperature variations found in shunted solar cells is too low.

In a Nematic LC (NLC), the optical axis is parallel to the long molecular axis, which in the planar texture is parallel to the film surface. When normally incident plane polarised light passes through such a film it is elliptically polarised. For regions of the film above the *clearing temperature*, defined as the temperature at which the NLC enters the isotropic (liquid) phase, the polarisation of the incident light is unchanged.

Therefore, when NLCs are applied to the surface of a solar cell, areas of the solar cell above the clearing temperature appear dark when illuminated with plane polarised light and viewed through a crossed polarising analyser. Heating the device under test to just below the clearing temperature enables temperature differences as low as 0.1°C to be detected with a spatial resolution of 1 µm² [6]. Such a precise result is only possible because the p-n junction is only about 1µm under the surface.

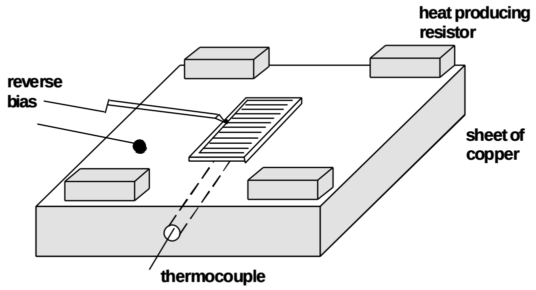
## 3. EXPERIMENTAL SET-UP

For good results it is necessary to have a very thin layer of NLC, which can be achieved by dropping it in the middle of a spinning device. Depending on the revolutions per minute and the spinning-time, the cell can be covered with a layer thinner than 25µm. The NLC used for this experiment has a clearing temperature of 29.0°C, which is close to room temperature and therefore avoids the need for a complex temperature control system.

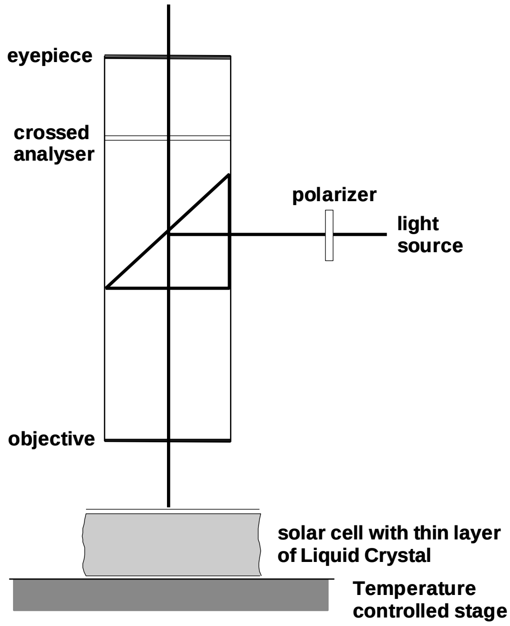
The experimental set-up is shown in Figure 1. It consists of a temperature controlled stage with an electrical probe on which to place the sample and a polarising microscope (a microscope with a plane polarised reflection mode light source and a plane polarising analyser).

The temperature controlled stage consists of a copper sheet (150x200x6 mm), where the high thermal conductivity (390 Jm/sK) is used to form a homogenous temperature throughout the whole solar cell and its surface. Four heat producing resistors (25W) on the edges warm the copper plate to a temperature just below the transition temperature of the NLC. A thermocouple placed in the middle of the stage with a temperature controller allows the temperature of the solar cell to be accurately controlled. With a probe and the copper block as a back contact the cell can be reverse biased. With the polarising analyser crossed with respect to the light source polarisation, regions of isotropic phase appear black.

It is useful to first view the solar cell with a very low magnification objective (2.5x or lower) and relatively high reverse bias current to get a rough idea where to find any dark regions. A Polaroid Camera or a Digital Camera captures pictures of the investigated surface.




(a)




(b)

**Figure 1: (a)** Schematic of the thermal stage used to heat the sample; **(b)** Polarised light source and detection.

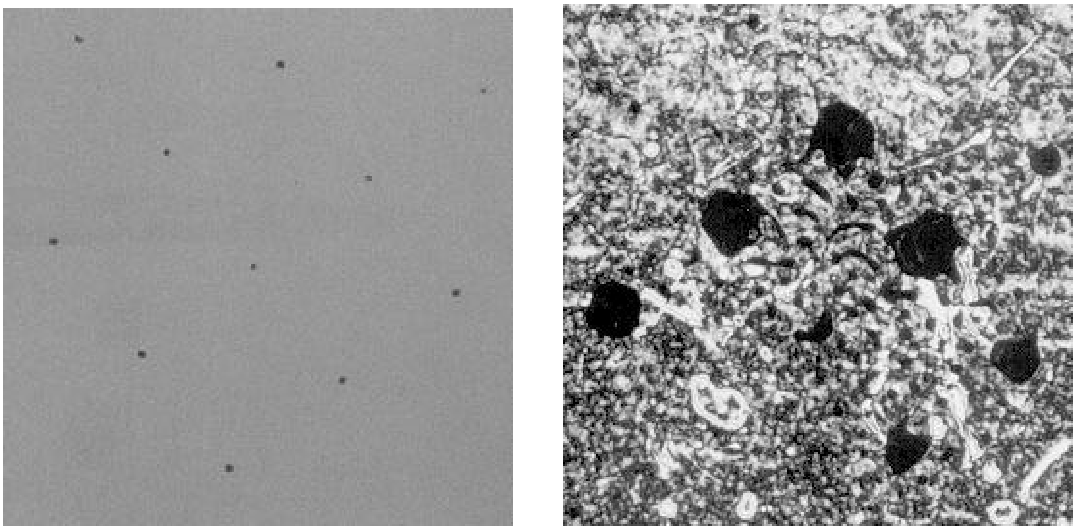
## 4. EXPERIMENTAL RESULTS

To demonstrate the viability of the method, a device was fabricated which contained a grid of shunts deliberately introduced into the emitter of the solar cell. These shunts were formed by sintering an array of evaporated Al dots, with 250 µm spacing. The lumped shunt resistance for the array is 63 kΩ. The NLC was spun onto the surface of the wafer. The device was placed onto the thermal block, reverse biased and heated until just below the transition temperature of the NLC. The results are shown in Figure 2(a) and (b).

Having demonstrated the viability of the technique, the method was applied to a buried contact solar cell. The lumped parameter shunt resistance for this device was measured as 20 Ωcm². The results using NLCs are shown in Figures 3 and 4. In Figure 3(a) the cell is unbiased, with the temperature set just below the clearing temperature. In Figure 3(b), the microscope picture shows a large black region which heated to the clearing temperature before the remainder of the device and corresponds to the shunt resistance.

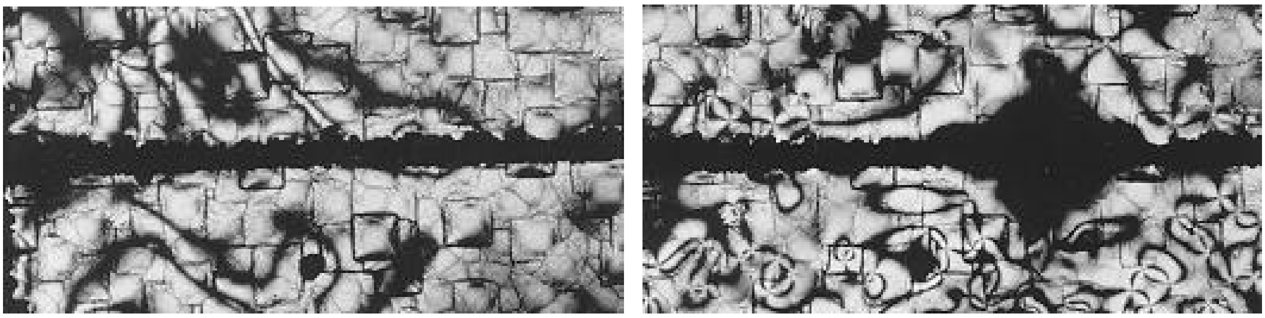
Under closer examination (Figure 4) the exact region could be identified. Figure 4(a) shows the unbiased device. Figure 4(b) shows the device just at the onset of the change in the NLC. Under further current increases, the large dark area shown in Figure 3(b) proceeded to expand from the small dark region shown in Figure 4(b). The ability to pinpoint the start of the dark area allows the location of the shunt to be precisely determined.

These micrographs show that the approximate location of a shunt can be quickly determined by reverse biasing the device to a high current so that the “black” area is large and easy to identify under low magnification. The precise location can then be found under higher magnification using a lower reverse bias current.



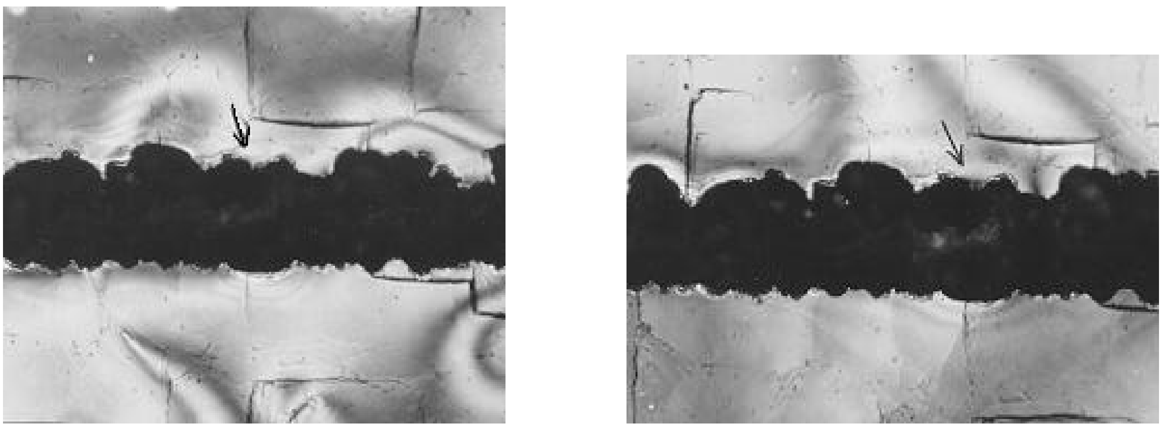
**(a)** **(b)**

**Figure 2**: Micrographs showing the metallised shunts. **(a)** Unbiased, without NLC film and viewed with unpolarised light; **(b)** NLC film on surface, viewing with the illumination and analysing polarisers crossed and a reverse bias of 13.5V (8.7mA). The dark areas corresponds to regions of higher temperature caused by heat generation in the shunt resistance and/or the spreading resistance into the shunt.



**(a)** **(b)**

**Figure 3:** Examination of a NLC coated buried contact solar cell. The micrographs show a metal groove under low magnification. The images are approximately 900 µm x 450 µm. **(a)** Unbiased; **(b)** Reverse biased to a current of 150 mA.



**(a)** **(b)**

**Figure 4**: Close-up of the shunted region, **(a)** unbiased; **(b)** biased.

The arrow on the photographs identifies the location of the shunt. These micrographs show that the location of the shunt can be precisely pinpointed. The area shown in these micrographs is 160 µm x 110 µm.

## 5. CONCLUSION

A new method of shunt location in solar cells using Nematic Liquid Crystals has been demonstrated. The results show that the technique can identify the location of either single or multiple shunts with a spatial resolution of several µm.

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