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A novel liquid crystal temperature sensor based on modal control principle

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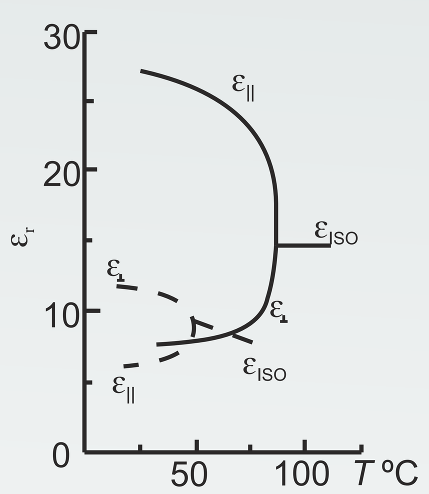
Introduction

The well-known electrically-controlled anisotropic properties of liquid crystals not only have been valued in displays applications, but also have led to the conception of innovative approaches for a wide and diversified field of applications, such as optical communications, imaging, metamaterials, microwaves, biomedical, etc. Also, the fact that liquid crystals parameters have a strong dependence with temperature, has allowed researchers to extend the design of liquid crystal devices into the field of sensors.

In this work, we propose the implementation of a novel kind of liquid crystal temperature sensor, based on a conventional interdigitated comb electrode structure with a µm-scale size and filled with a Nematic Liquid Crystal (NLC). The structure of the sensor includes a nanometric layer by deposition of Nickel. This sensor has demonstrated high temperature sensitivity that, in addition to low power consumption, improves sensor features in relation to other reported temperature sensors.

Principle of Operation

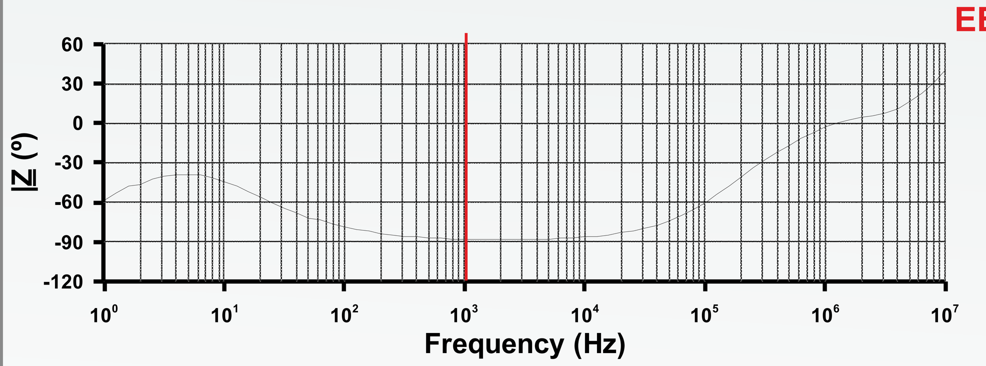
The NLC permittivity is heavily dependent on temperature:

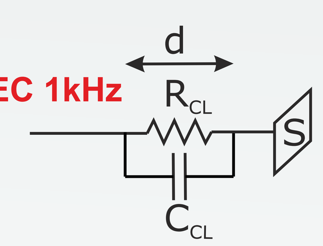


How can this NCL characteristic effect be exploited?

How can this effect be increased?

Study of the Merck MDA98-1602 nematic LC with a Solartron 1260 Impedance/Gain-Phase Analyser:

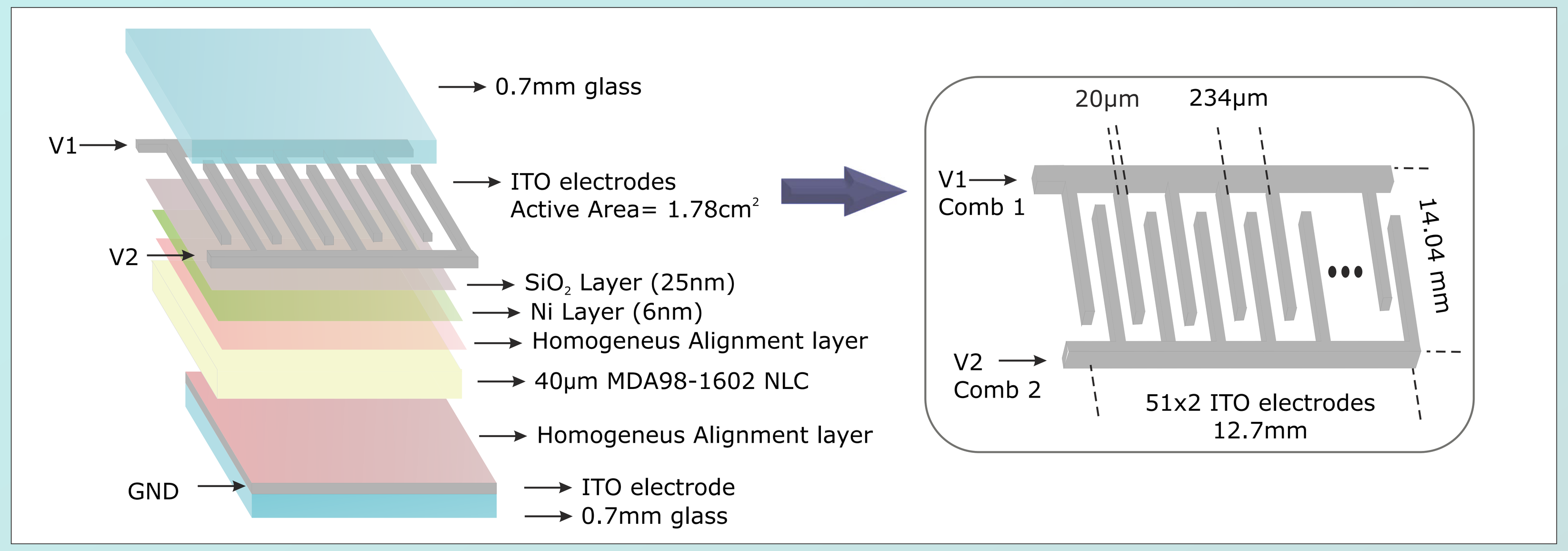




$$C_{CL}=\frac{\varepsilon_0\varepsilon' S}{d},\quad G_{CL}=\frac{1}{R_{CL}}=\frac{\varepsilon_0\varepsilon''\omega S}{d}$$
$$Z_{CL}=\frac{1}{j\omega C_{CL}},\quad Z_{R_{CL}}=R_{CL} \qquad (1)$$

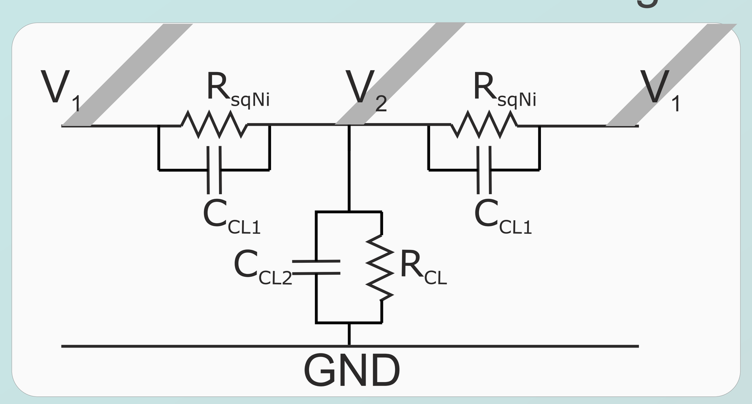
- We could exploit the temperature effect using the electrical components of the Equivalent Electrical Circuit (EEC).
- As can be seen on Eq. 1 the distance has to be very small in order to have low impedances.
- We can improve the temperature permittivity dependence if the conductivity ($\sigma=\varepsilon_0\varepsilon''\omega$) of the EEC is increased.

Topology & Analytical Study



- Two interlaced combs are designed. The first one (Comb 1) act as voltage source. The Comb 2 measures the voltage drop at the central point between two tooths of the Comb1.
- The distance between electrodes is 117µm, achieving low impedances (Eq. 1).
- The device conductivity is increased by depositing Nickel that forms aggregated Nanoparticles (NP) onto a SiO_2 layer by an evaporation process.

The result is a distributed voltage divider:



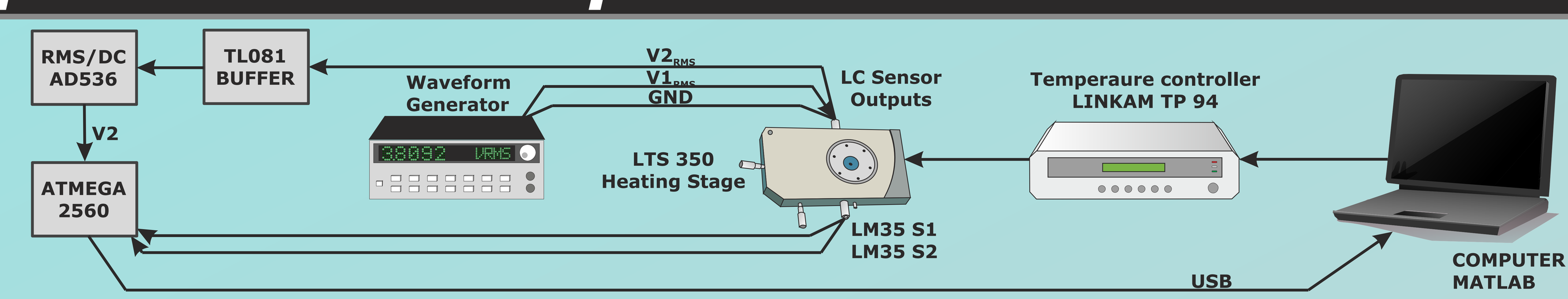
$$\frac{\partial V^2(x)}{\partial x^2}=\frac{C_{CL2}+1/R_{CL}}{1/R_{sqNi}+C_{CL1}}\cdot V(x) \qquad (2)$$

Considering V(-r)=V(r)=V_1 and V(0)=V_2:

$$V_2=\frac{V_1}{\cosh\left(\frac{\sqrt{R_{sqNi}\varepsilon_0\varepsilon_{CL}\omega}\cdot r}{2t_{CL}}\right)} \qquad (3)$$

- The conductivity of the Ni layer is modelled as a resistor (R_{sqNi}). The parallel resistor of the NLC is higher than R_{sqNi} so it is negligible.
- On Eq. 3, V_1 is the applied voltage, V_2 the measured voltage, R_{sqNi} the sheet resistance produced by Ni, r is the distande between the electrodes, and t_{CL} the LC thickness.

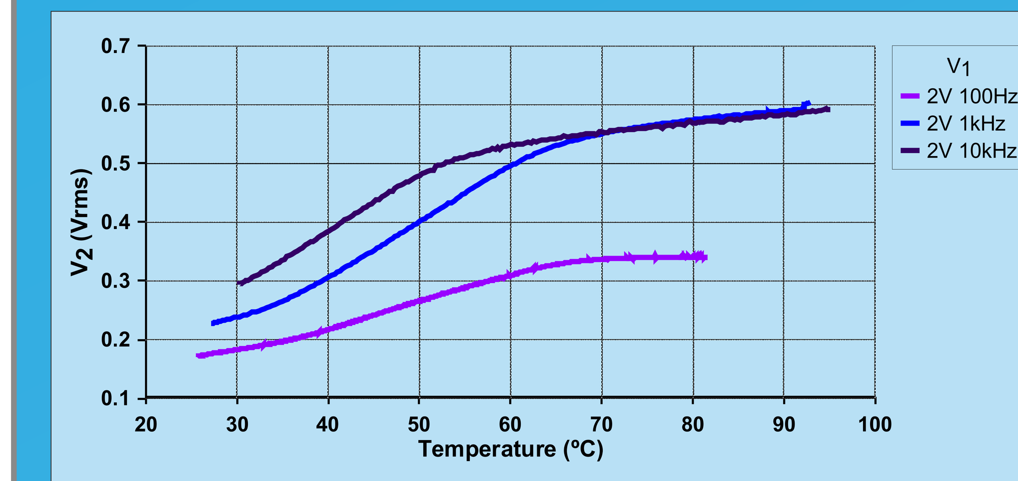
Experimental Setup



- The experiment consists of increasing temperature 1ºC/min, taking 3 samples/min.
- LM35 temperature sensors measure the temperature inside the stage.
- $V2_{RMS}$ is connected to a TL081 based buffer and converted to a DC signal by an AD536 RMS/DC converter.
- V2, S1 and S2 are connected to analog inputs of a microcontroller, also connected to PC trough a USB cable. A MATLAB program processes all data.

Experimental Results

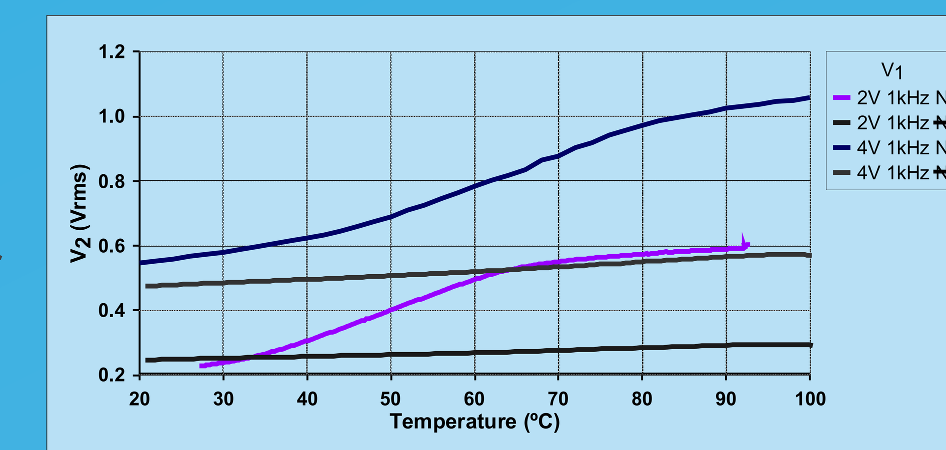
Frequency dependence

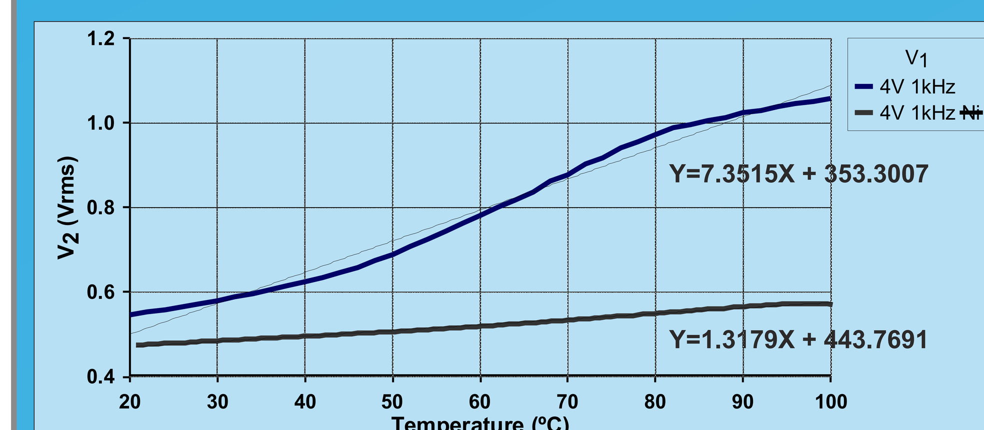


- For 1 kHz the sensitivity is maximum.
- At this frequency the real permittivity is predominat so, one reason of this behavior could be greater changes of the real permittivity (ε') with temperature than the imaginary permittivity (ε'').

Is really working the Nickel nanometric layer?

- The voltage affects the sensitivity, probably because the extraordinary component is more temperature dependent ($\varepsilon_e(T)>\varepsilon_o(T)$).
- In order to demonstrate the Ni NP effect, another device with the same characteristics but without Ni layer is manufactured and characterized.





- The temperature sensitivity of the device with the Ni NP layer is almost seven times greater.
- This result demonstrates how the permitivity change with temperature is improved.
- R_{sqNi} in Eq. 3 is suggested to be temperature dependent, $R_{sq}(T)$, in addition to ε(T).

Conclusions & Future Directions:

- **The LC sensor shows that the output voltage's sensitivity to temperature response can be controlled by either the magnitude or the frequency of the applied voltage.**
- **For certain supply voltages, this sensor has demonstrated high temperature sensitivity that, in addition to low power consumption, improves sensor features in relation to other reported temperature sensors.**
- **This sensor could be used in LCD displays, LCD projectors, portable equipment or any application where its properties get an advantage with respect to current available sensors.**
- **An homeotropic aligment would make better use of the temperature permitivity dependence, because the maximum sensitivity would be for low voltages (low V_1→Low Power)**
- **The inclusion of more quantity of Ni NP could improve the sensitivity of the sensor (↑R_{sqNi}).**
- **This work has presented and characterized a novel idea, and opened new avenues for research on temperature sensors.**

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The well-known electrically-controlled anisotropic properties of liquid crystals not only have been valued in displays applications, but also have led to the conception of innovative approaches for a wide and diversified field of applications, such as optical communications, imaging, metamaterials, microwaves, biomedical, etc. Also, the fact that liquid crystals parameters have a strong dependence with temperature, has allowed researchers to extend the design of liquid crystal devices into the field of sensors. The simultaneous effect of both dependences, on voltage and temperature, has been recently exploited in a novel frequency-temperature liquid crystal transducer [1].

In this work, we propose the implementation of a novel kind of liquid crystal temperature sensor, based on a conventional interdigitated comb electrode structure with a micrometer-scale size. The conformation of the sensor includes a high resistivity layer (modal control) by deposition of a metallic layer (Nickel) of nanometric thickness. The benefit derived from using the modal method is the generation of a customized impedance divider between the metallic layer and the liquid crystal. Some results can be observed in Figure 1. It shows that the output voltage's sensitivity to temperature response can be controlled by either the magnitude or the frequency of the applied voltage. For certain supply voltages, this sensor has demonstrated high temperature sensitivity that, in addition to low power consumption, improves sensor features in relation to other reported temperature sensors. The proposed structure can be improved by some constructive changes. Characterization results suggest that this novel type of sensor can be employed in some specific commercial applications such as liquid crystal projectors or displays.

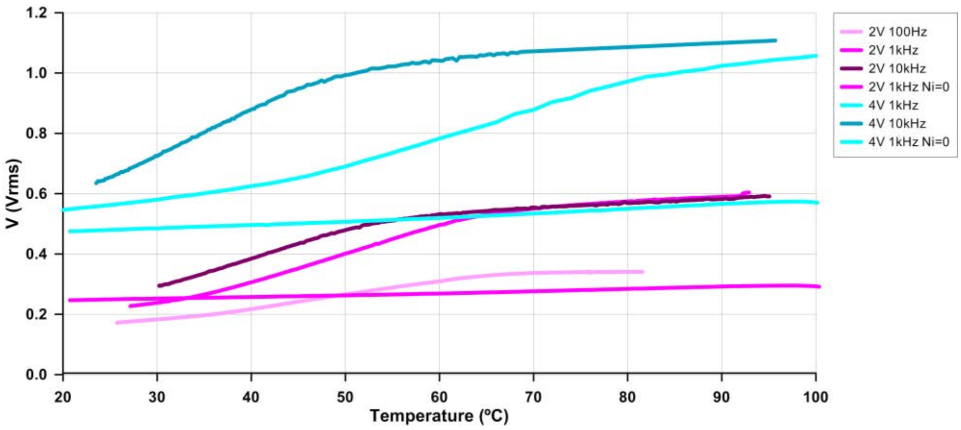

Figure 1. Frequency and voltage (rms) dependence of liquid crystal sensor response as temperature increases from 20ºC to 100ºC.

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