Design of a semiconductor thin-film thermocouple fabricated by pulsed laser deposition

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Abstract. Silicon is one of the most used substrates for the deposition of thermoelectric materials as thin films. In this work, we report the design of a thermocouple based on thin films (in this case a pair of semiconducting copper-based chalcogenides[1], but it works for any kind of thin films) fabricated by pulsed laser deposition (PLD) on silicon wafers. Taking into consideration that charge transport is enhanced in the direction parallel to the surface of the film, two gold electrodes were deposited by sputtering on each thin film, the rest of the film being protected by Kapton tape (for electrical and thermal insulation, and increased mechanical resistance). Upon applying a conductive paste between the gold electrodes from each film, a thermocouple is formed. An extra gold electrode applied on Kapton tape is used as inter-connect between two thermocouples. A thermal insulator layer can be applied between the thermocouples, in order to maintain the thermal gradient between the two sides. The idea is to be able to connect multiple such pairs in line, in order to fabricate a miniaturized thermoelectric device [2].

Thin films fabrication:

- Thin films of copper-based chalcogenides have been deposited by PLD[2], on 10x10x0.5 mm Silicon wafers: Cu_3SbSe_3, as *n*-type semiconductor and Cu_3SbSe_4, as *p*-type semiconductor (see Fig. 1)
- Deposition parameters:
  - laser fluence 1.5 J/cm^2, frequency 2Hz;
  - Substrate temperature: 350°C for Cu_3SbSe_3 and room temperature followed by annealing at 300°C, for Cu_3SbSe_4
  - High vacuum (10^{-6} – 10^{-7} mbar)

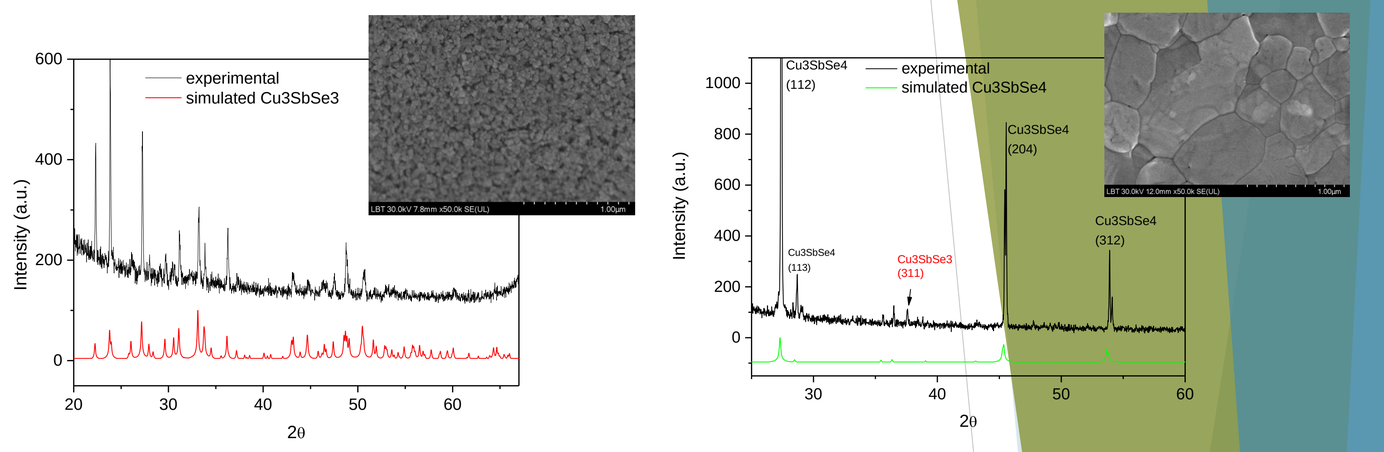

Figure 1. XRD diffraction patterns for the thin films deposited on Si (100)
(inset on each figure represents the SEM image of the thin film thus obtained)

Experimental details on the design of the thermocouple:

- Copper masks have been fabricated and gold contacts have been deposited by sputtering on the surface of the thin films (as presented in Fig.2), and on Kapton tape (which are further used as contacts);
- A *n*-type semiconductor thin layer, with gold contacts, is connected to a p-type semiconductor one, in series, using silver paste, for electrical conductivity; the rest of the films being protected with Kapton tape (an electrical insulator, with good stability at high temperatures) (the schematic representation is presented in Fig.3, and the actual thermocouple in Fig. 4, which is then connected to a PCB);
- Several such thermoelectric modules can be coupled on the same PCB, to increase the power generated by this type of devices;
- In order to measure the electrical output for the thermocouple, a temperature gradient has to be applied on top and bottom of the device (the device put on a hot plate, with known temperature, and the upper part in air, in ambient conditions);
- The thermoelectric measurements for the system are planned in the foreseen future;
- The thermoelectric device obtained from such thermocouples has a small volume, which makes it suitable for small, portable or wearable devices.

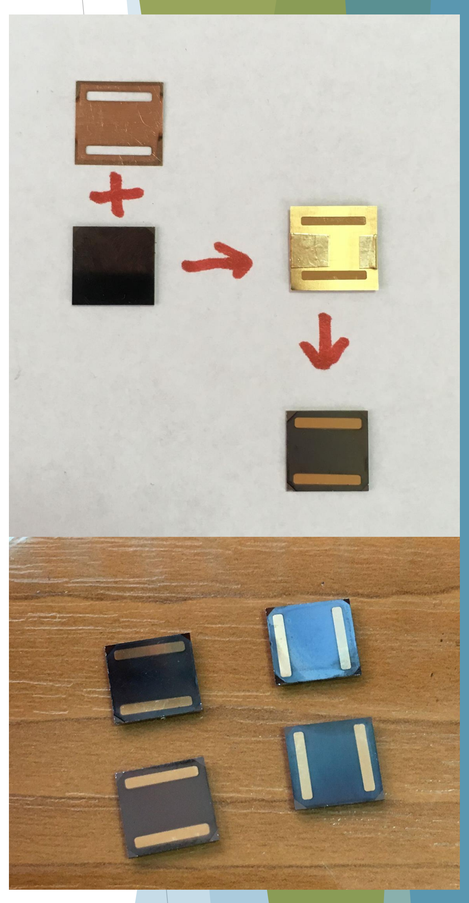

Figure 2. Thin films with gold contacts obtained by sputtering

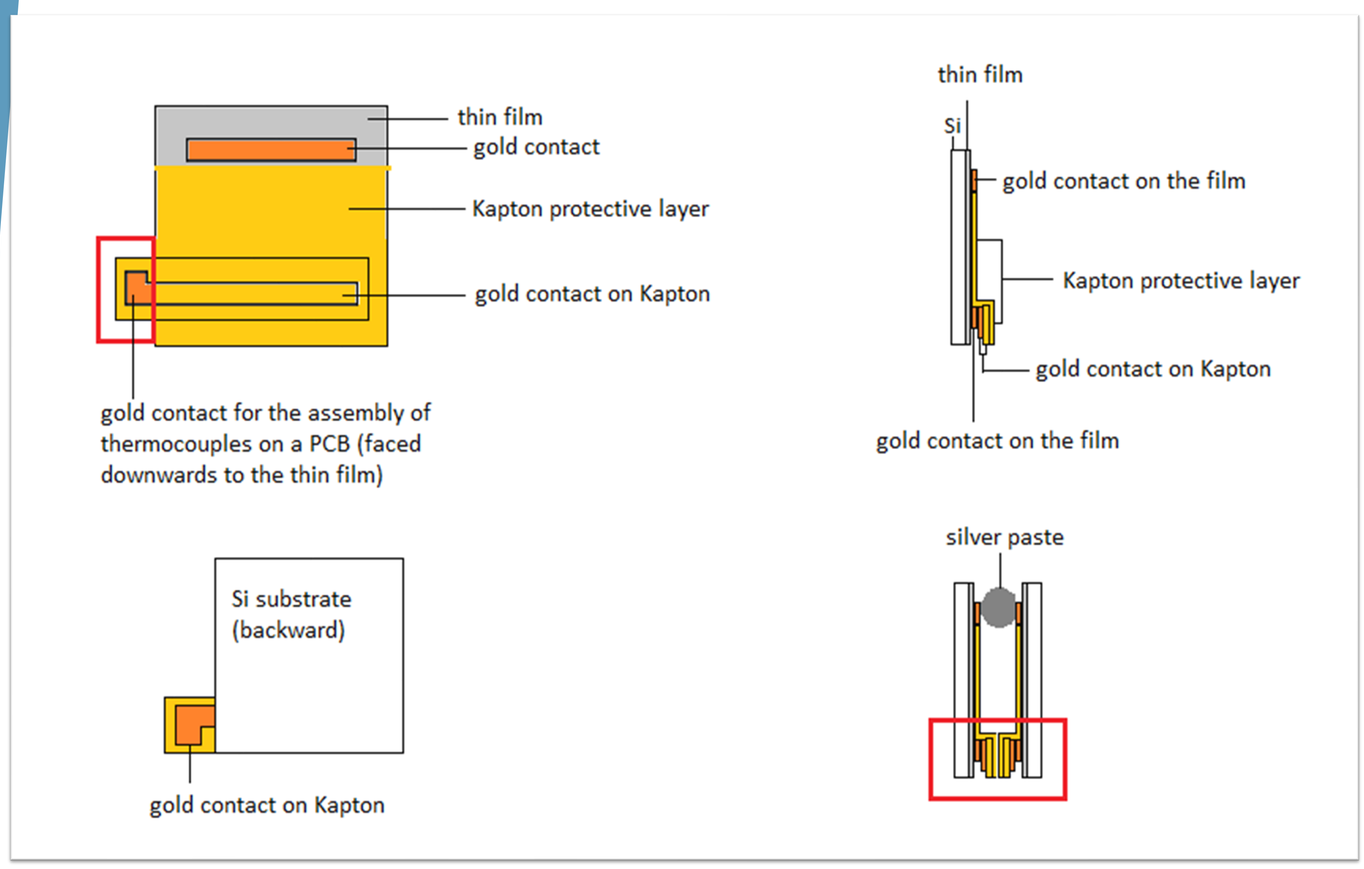

Figure 3: Schematic representation of the construction of the thermocouple

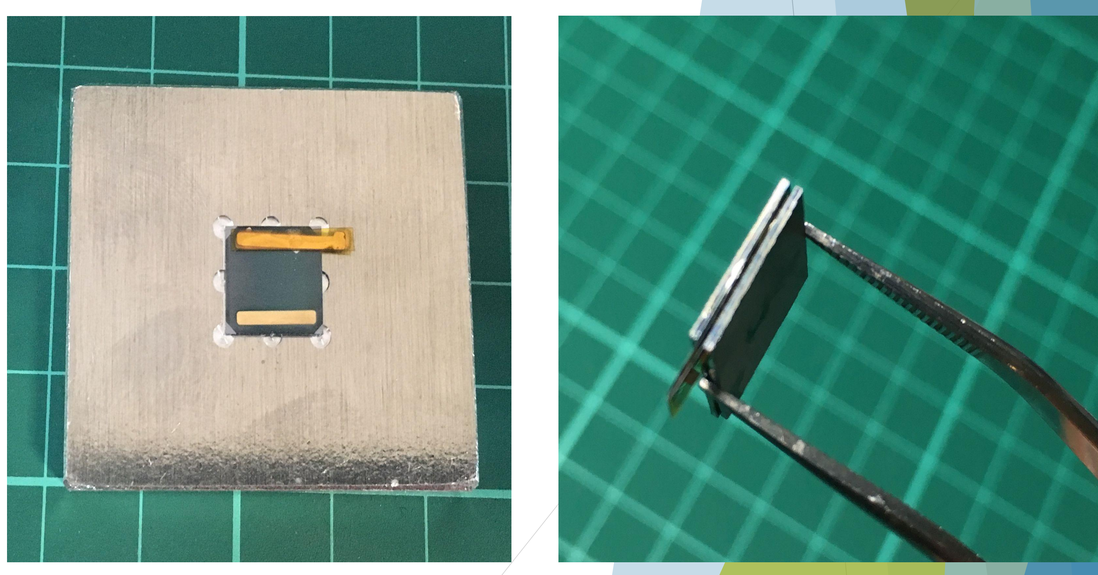

Figure 4. A thin film with gold contact and a contact on Kapton (left image)
The designed thermocouple (10x10x6mm – right image)

Conclusion: Thin films of known thermoelectric materials (copper-based chalcogenides) have been fabricated by PLD, on Si (100). These films have been used for the design of a thin films thermocouple. There are some limitations concerning the small dimension of the structure, the operating temperature, the thermal isolation of the superior and inferior parts. Thermoelectric measurements on the device are planned in the near future.

Refrences:
1. Tian-Ran Wei et al., Sci China Mater 2019, 62(1): 8-24
2. G. Jeffrey Snyder, Eric S. Toberer, Nat. Mater. 7 (2008) 105-114
3. S. Garabagiu et al, Materials Letters 2019, 243, 125-127

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