Carbon Dioxide as Thermal Fluid in Micro Systems

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Primary CNF Tools Used: AJA sputter deposition, chemical mechanical polishing (CMP)

Summary:

Carbon dioxide (CO_2) is a natural coolant that present an alternative for environmentally hazardous coolants like hydrocarbons. The highest potential of CO_2 is in the trans critical region where it's thermophysical properties exhibit largest variations. For example, CO_2 viscosity lowers significantly during transition from liquid to supercritical phase, such reduction enables to reduce the pressure drop inside a micro channel and to achieve higher mass fluxes leading to a better heat removal. The project goal is to fabricate a microfluidic device that will enable to better understand thermal behavior of CO_2 in the vicinity of the critical point — a temperature and pressure of 31.4°C and of 7.37 MPa, respectively. This requires the microfluidic device to function under high pressure.

The part that was fabricated at CNF is shown in Figure 1. It has heaters and resistor temperature detectors (RTDs) depicted as the white and brown layer, respectively. These layers were deposited using AJA sputter deposition tool, and then separated and sealed using silicon oxide that was applied using plasma enhanced chemical vapor deposition (PECVD).

To achieve good sealing of the microdevice, the top surface was polished using chemical-mechanical polishing process. The wafer was then placed in a DISCO dicing saw to separate the devices. With the AJA sputter tool and the help of the CNF staff we were able to achieve very high repeatability in respect to electrical resistance. To minimize fluid leakage, the top surface was polished to an average roughness of 150 nm. This helped ensure a leakage of several orders of magnitude smaller that the intended mass flow inside the device.

Figure 2 presents the microdevice assembly where the bottom substrate has the control components (i.e., the heaters and the RTDs) and the top substrate has the microchannel. The top substrate is made of fused silica to allow optical access to the microchannel.

Figure 3 presents an image of flow patterns at different phases — gas, liquid, and supercritical. The applied heat flux is 17 W/cm^2, the inlet temperature is 23°C, and the mass flux is 500 kg/m^2s for all images. The pressures are 5.34 MPa, 6.6 MPa and 8 MPa for gas, liquid and supercritical respectively. For the liquid phase there is formation of bubbles inside the channel which corresponds to heat removal by boiling. Bubble inside pressure is inversely proportional to its diameter,

Therefore, due to high operating pressure the bubbles are small. In the images of the gas and supercritical phases, vertical lines can be seen. The lines correspond to equal density, which are dependent on the refraction index, and therefore visible using the camera. For the supercritical phase the lines are more distinct corresponding to larger variation of the density due to local heating. These density variations promote mixing, and therefore, enhance the heat transfer at the supercritical phase. It was found that the heat transfer coefficient of supercritical phase was enhanced by approximately 20% compared to the gas phase.

Our future work includes further investigation of heat transfer patterns at the trans-critical region. Gaining better understanding of the mechanisms controlling the heat transfer process will enable to have more efficient thermal control in microsystems.

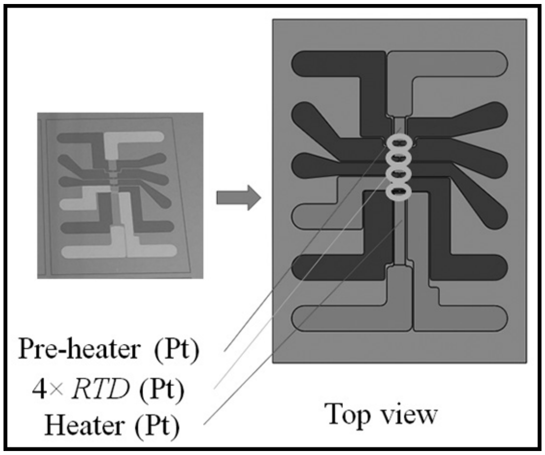

Figure 1: The microfabricated piece.

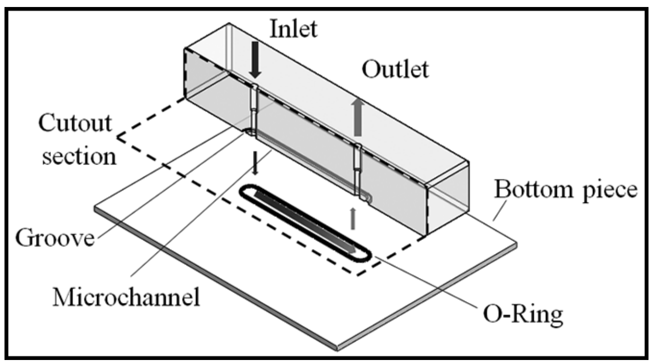

Figure 2: Microdevice assembly.

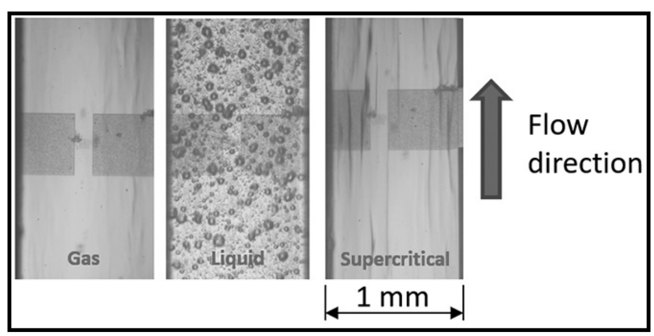

Figure 3: Heat transfer patterns at for different phases of CO_2.