Ground Experiments on a Liquid Bridge Facility for TG-2 Space Laboratory

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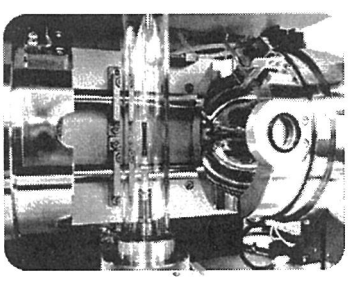
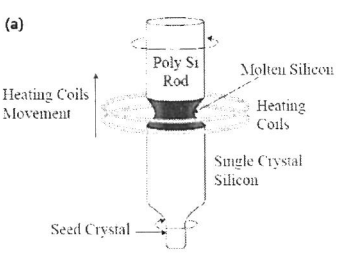
1. Introduction

1. **The crystal growth on ground is limited by gravity, Microgravity environment in space provide a good condition for growing large scale crystals. But, it is also influenced by surface tension.**
2. **In order to discuss how the surface tension influence the crystal growth, the small scale liquid bridge usually 3-5mm in diameter has been studied for many years as an experiment model on ground.**
3. **It has much difficulty to establish a large scale liquid bridge on ground, especially with large aspect ratios.**

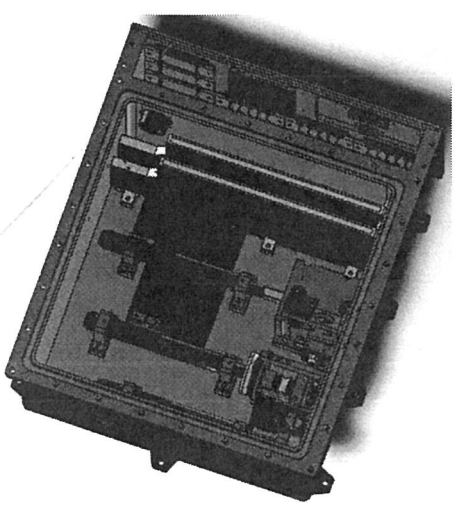




2 The chief contents of the present research work

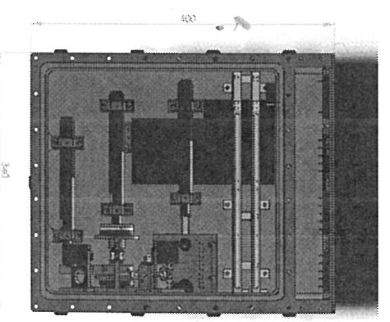
1. **The thermocapillary convection of a large scale liquid bridge 20mm in diameter will be studied on TG-2 Space Laboratory in 2016, the influence of aspect ratio and volume ratio to the critical process of convection will be analyzed, and then the second transition will be discussed.**
2. **The space experiment equipment has been assembled, the thermocapillary convection in this large scale liquid bridge with small aspect ratios has been studied on ground, it will be references for space experiment on TG-2.**

3 Design of the equipment



Including:

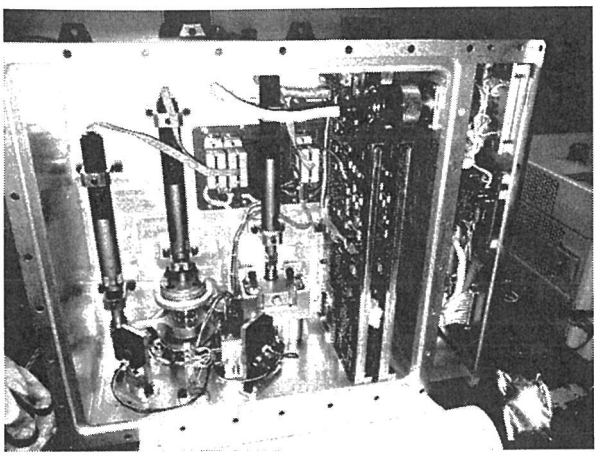
1. **Liquid bridge**
2. **Liquid reservoir and infusion**
3. **Clearing system**
4. **Temperature-control system**
5. **Tempertuure-measure system**
6. **Light**
7. **Image acquisition**
8. **Electronic-control system**



4. Equipment

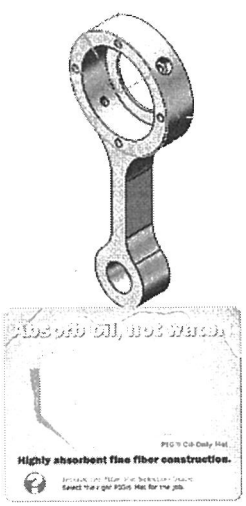
340mm×150mm×400mm

13Kg

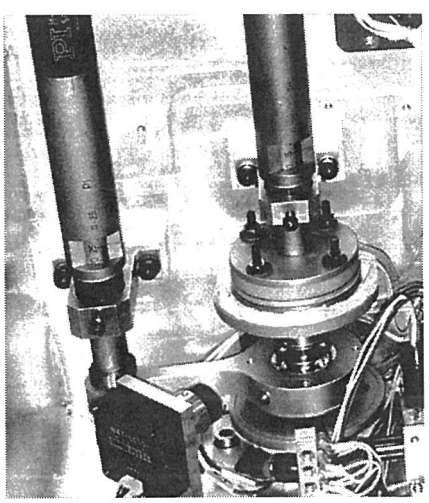


1. The bridge diameter = 20mm
2. The upper bridge could be driven up and down by a PI motor.
3. The silicon oil is injected from the center hole of the down bridge by controlling the piston of hydraulic cylinder, which is driven by another PI motor.
4. The two CCD cameras are used to monitor the liquid bridge.

4. Equipment

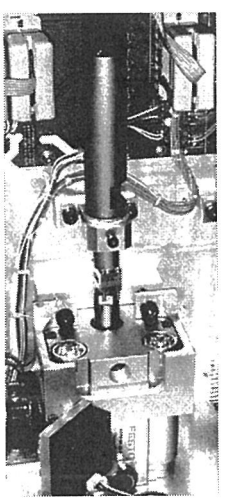


Highly absorbent fine fiber construction



Liquid bridge

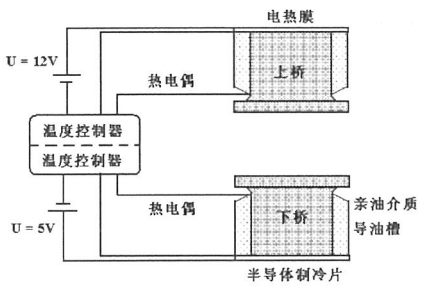
Clearing system



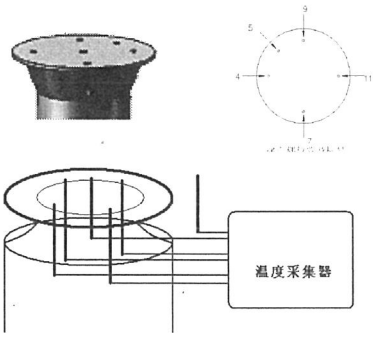
Liquid reservoir and infusion

4. Equipment

- Temperature-control system : **The temperature difference is imposed by heating the upper bridge and cooling the down bridge.**
- Temperature-measure system : **Five thermocouples are used to measure the temperature of the liquid, they are placed at the same circle （⌀=15mm） and the same height to the down bridge column （⌀=2mm） in liquid.**



Temperature-control system

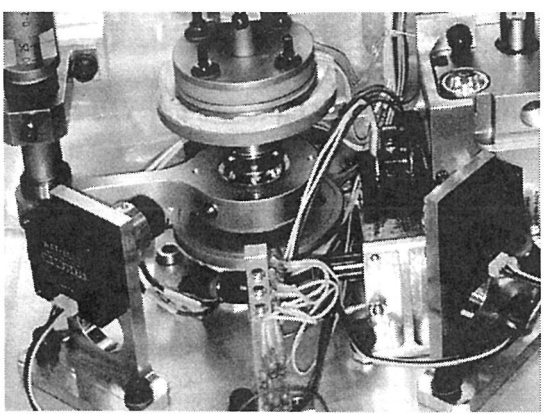


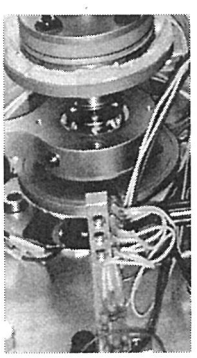
Temperature-measure system

4. Equipment

Light:

- **Three LED lamps are connected in parallel for lighting the environment in box**





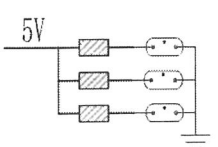


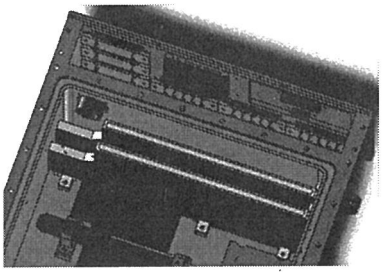
Image acquisition :

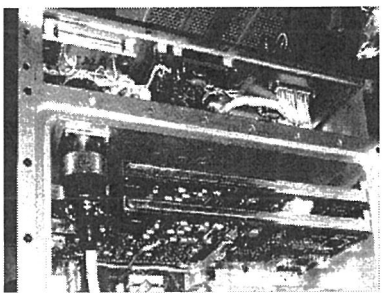
- **2 CCD, close shot, long shot**
- **D1(720×576)@25fps**
- **The rate of video data <3Mbps**

4. Equipment

Electronic-control system:

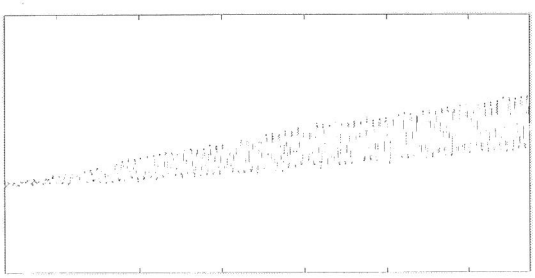
- Primary power source: 29V
- Secondary power supply: 5V, 12V
- Communication: RS422 for scientific data transmission down to ground, for data injection up to Space Laboratory.
- Control PI motor
- Control the temperature difference between the two bridges
- Control temperature measurement
- Control LED lamps, and control Image acquisition.
- Control the space experiment

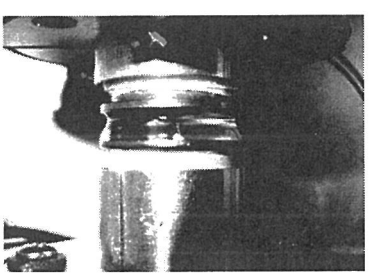




5. Ground Experiment Results—The oscillation

- Liquid: silicon oil, 2cSt (Pr =28)
- h = 4mm, V/V0=0.9.
- The down bridge is kept at the temperature of the surrounding environment.
- The temperature of the up bridge is increased at the rate of 0.005°C/s.
- The measurement sensitivity is 0.03 °C
- With the increasing of the temperature difference, the temperature oscillation appears.





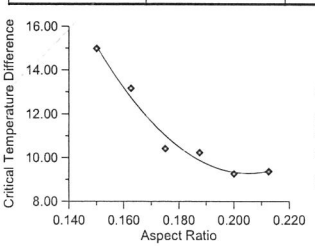
h=4mm, Volume ratio V/V0=0.9

Five questions have been discussed

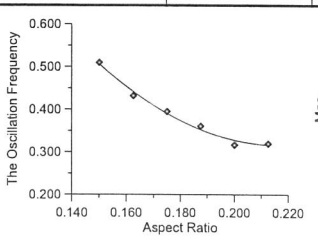
- Aspect ratio ($A=l/d$)
- Volume ratio (V/V0)
- Transition
- Phase
- Amplitude

5 . Results—(1) Aspect ratio ($A=l/d$) influences the ΔTc and oscillation frequency

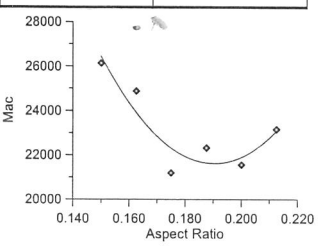
h/mm	V/V_0	Aspect Ratio	ΔT_c/K	Ma_c	f_1/Hz
3.00	0.9	0.1500	14.993	26143	0.510
3.25	0.9	0.1625	13.173	24884	0.432
3.50	0.9	0.1750	10.422	21202	0.395
3.75	0.9	0.1875	10.243	22326	0.361
4.00	0.9	0.2000	9.275	21564	0.317
4.25	0.9	0.2125	9.378	23166	0.320



ΔTc



Oscillation frequency



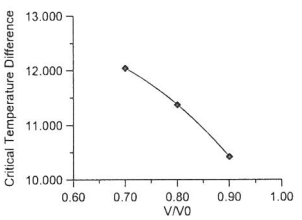
The critical Ma number

The aspect ratio is an important effect factor to thermocapillary convection.

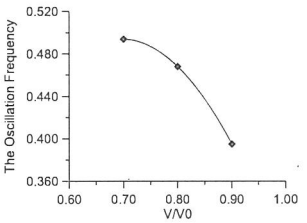
5 . Results—(2) Volume ratio (V/V0) influences the ΔTc and oscillation frequency

- Select the same thickness of the liquid layer, the bigger the volume ratio, the smaller the critical temperature difference is, and the smaller the frequency is.
- The volume ratio is an important effect factor to the thermocapillary convection.

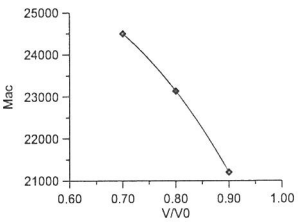
h/mm	V/V_0	ΔT_c/K	Ma_c	f_1/Hz
3.5	0.7	12.045	24503	0.494
3.5	0.8	11.374	23138	0.468
3.5	0.9	10.422	21202	0.395
3.5	1.0	irregular oscillation signal		



ΔTc



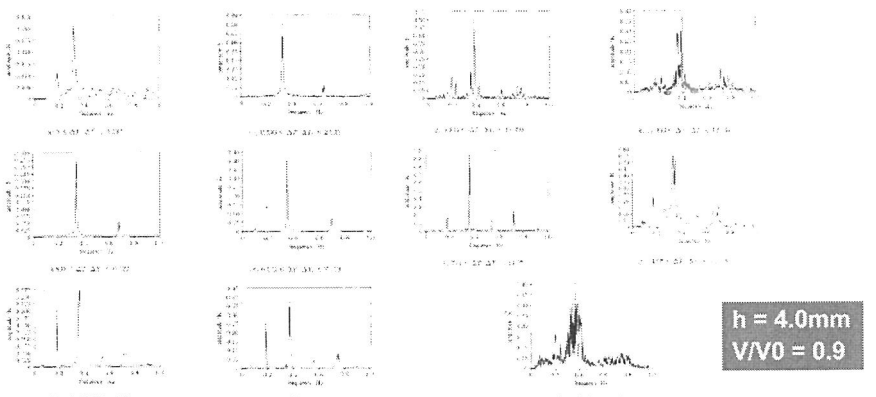
Oscillation frequency



The critical Ma number

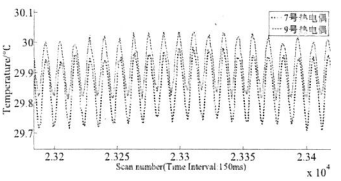
5 . Results—(3) Transition of Thermolcapillary Convection

- h = 3mm, 3.5mm, 3.75mm, 4.0mm, 4.25mm
- 3mm liquid bridge: appears f=kf0 (k=1,2) , and difference frequency.
- 3.5mm, 3.75mm liquid bridge: appears f=(k/2)f0 (k=1,2,3) , and difference frequency .
- 4.0mm, 4.25mm liquid bridge: appears f=(k/2)f0 (k=1,2,3,4,5) , and difference frequency.
- For different thicknesses of the liquid bridge, the different transitions appear.

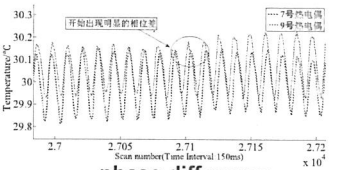


5. Results—(4) Phase

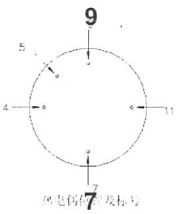
- At early stage of oscillation, the phases of five points oscillation are uniform， it demonstrates that the thermocapillary convection is symmetrical.
- With the increasing of the temperature difference, the phase has changed.
- To take the temperatures of two points of no. 7 and no. 9 for an example, their phase changes from phase-equal to phase difference , inverse phase, and then to a new phase difference.

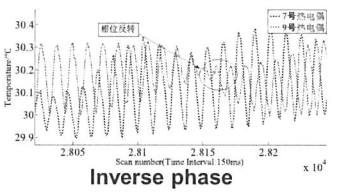


phase-equal

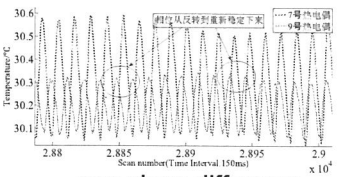


phase difference





Inverse phase

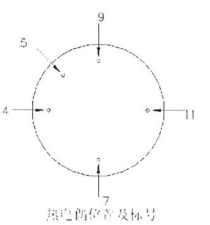


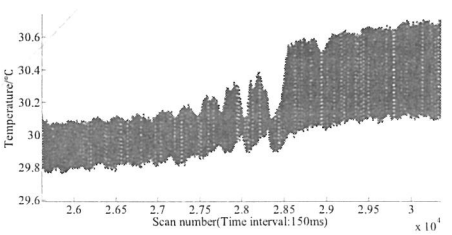
new phase difference

h = 3mm
V/V0 = 0.85

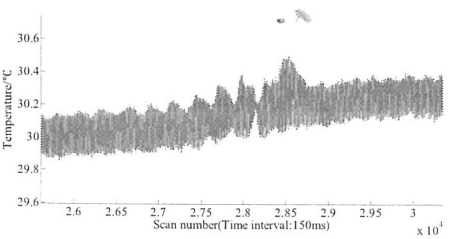
5. Results—(5) Amplitude

- Characters: The amplitude of no. 7 point doubles after the transfer, and the amplitude of no. 9 point does not change.
- It demonstrates that the thermocapillary convection is asymmetrical.





The temperature oscillation of no. 7



The temperature oscillation of no. 9

6. Summary

1. **An equipment of large scale liquid bridge for space experiment in TG-2 Space Laboratory has been assembled.**
2. **The ground experiment has been done, the aspect ratio, volume ratio, transition, oscillation phase and amplitude have been discussed.**
3. **At the same volume ratio, the higher the liquid bridge, the more nonuniform the temperature, the convection transients easily.**
4. **At the same aspect ratio, the smaller the volume ratio, the bigger the surface deformation, so the critical temperature difference and the oscillation frequency have been influenced.**
5. **With the increasing of temperature difference, the convection mode will changes.**

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