

# LTCC INTEGRATED MINIATURE Rb DISCHARGE LAMP MODULE FOR STABLE OPTICAL PUMPING IN MINIATURE ATOMIC CLOCKS AND MAGNETOMETERS

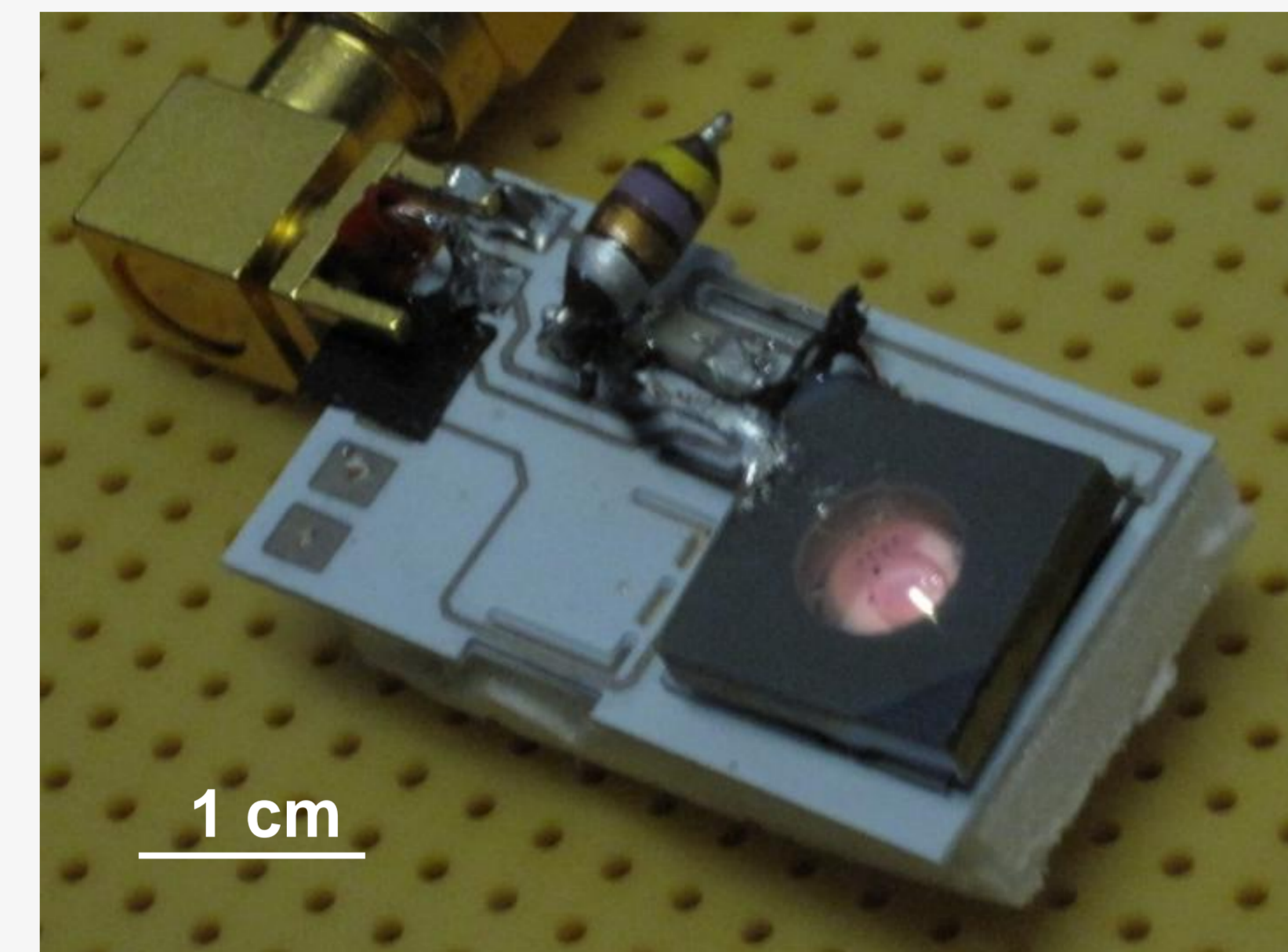
V. Venkatraman<sup>1,\*</sup>, F. Vecchio<sup>2</sup>, T. Maeder<sup>2</sup>, P. Ryser<sup>2</sup> and H. Shea<sup>1</sup>

<sup>1</sup>Microsystems for Space Technologies Laboratory (LMTS), EPFL, Neuchâtel, Switzerland

<sup>2</sup>Laboratory of Microengineering for Manufacturing (LPM), EPFL, Neuchâtel, Switzerland

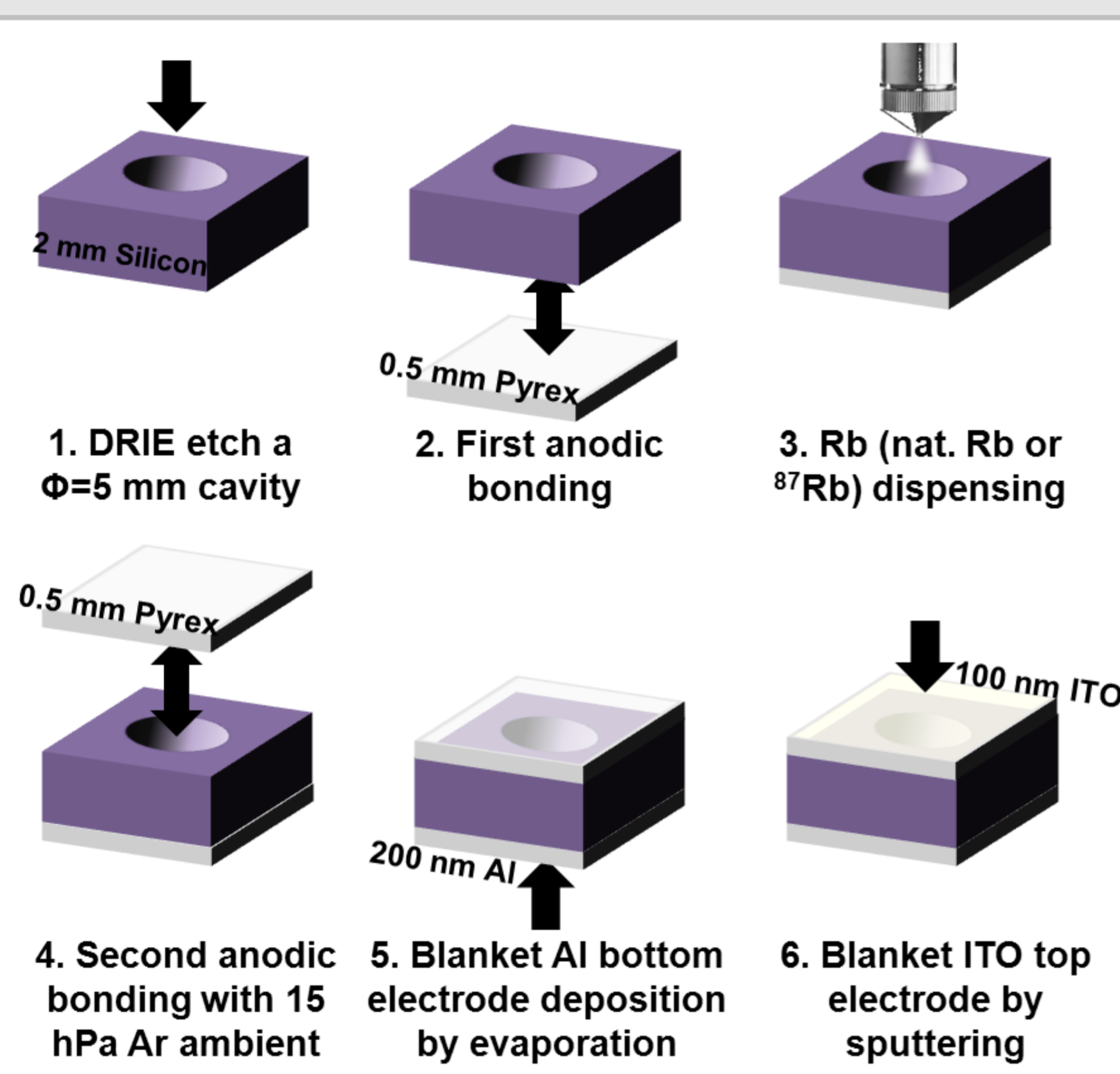
## MODULE DESCRIPTION

- ❖ We report here on an integrated mini Rb lamp module (15x26x4 mm<sup>3</sup>) for stable optical pumping in miniature-scale atomic clocks and magnetometers.
- ❖ The module is constituted of a microfabricated rf-powered Rb dielectric barrier discharge (DBD) lamp (10x10x3 mm<sup>3</sup>) positioned on top of a 0.6 mm thick (thickness adjustable) 4-layer LTCC (Low Temperature Co-fired Ceramic) stacked heater and rf drive circuit platform.
- ❖ The LTCC platform contains a serpentine heating resistor design with high heating capacity (up to several hundred degree Celsius) for lamp heating, a fast response DP 5092D PTC temperature sensor for temperature stabilization using PID feedback and a patterned pad layout for the drive circuit components and interconnects.
- ❖ This is the first report of an LTCC integrated Rb mini-lamp module.
- ❖ The novelties of this design include:
  - (1) compact module and independent heating design with thermal isolation of the drive components
  - (2) very low capacitive interference of the heating elements on the lamp electrodes leading to lower power coupling losses and higher optical power stability during pumping operation
  - (3) the components can be batch-fabricated and the module can be independently used for optical pumping in other applications including atomic gyroscopes

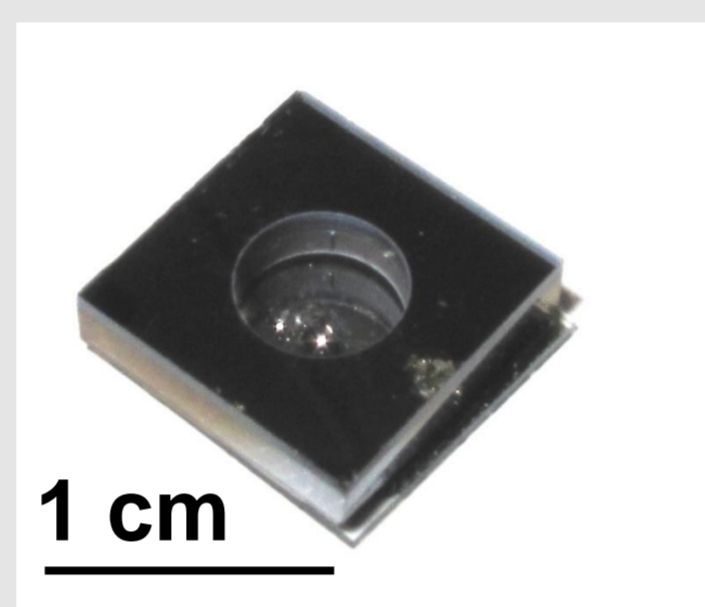


Rb mini-lamp module in operation

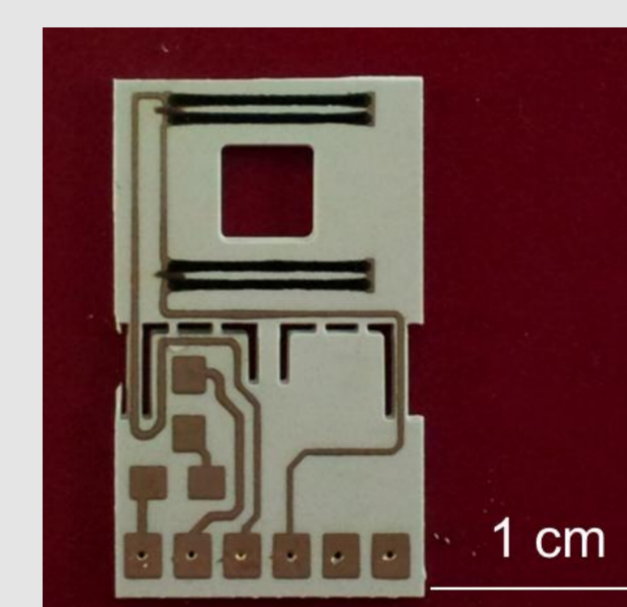
## COMPONENTS AND DEVELOPMENT



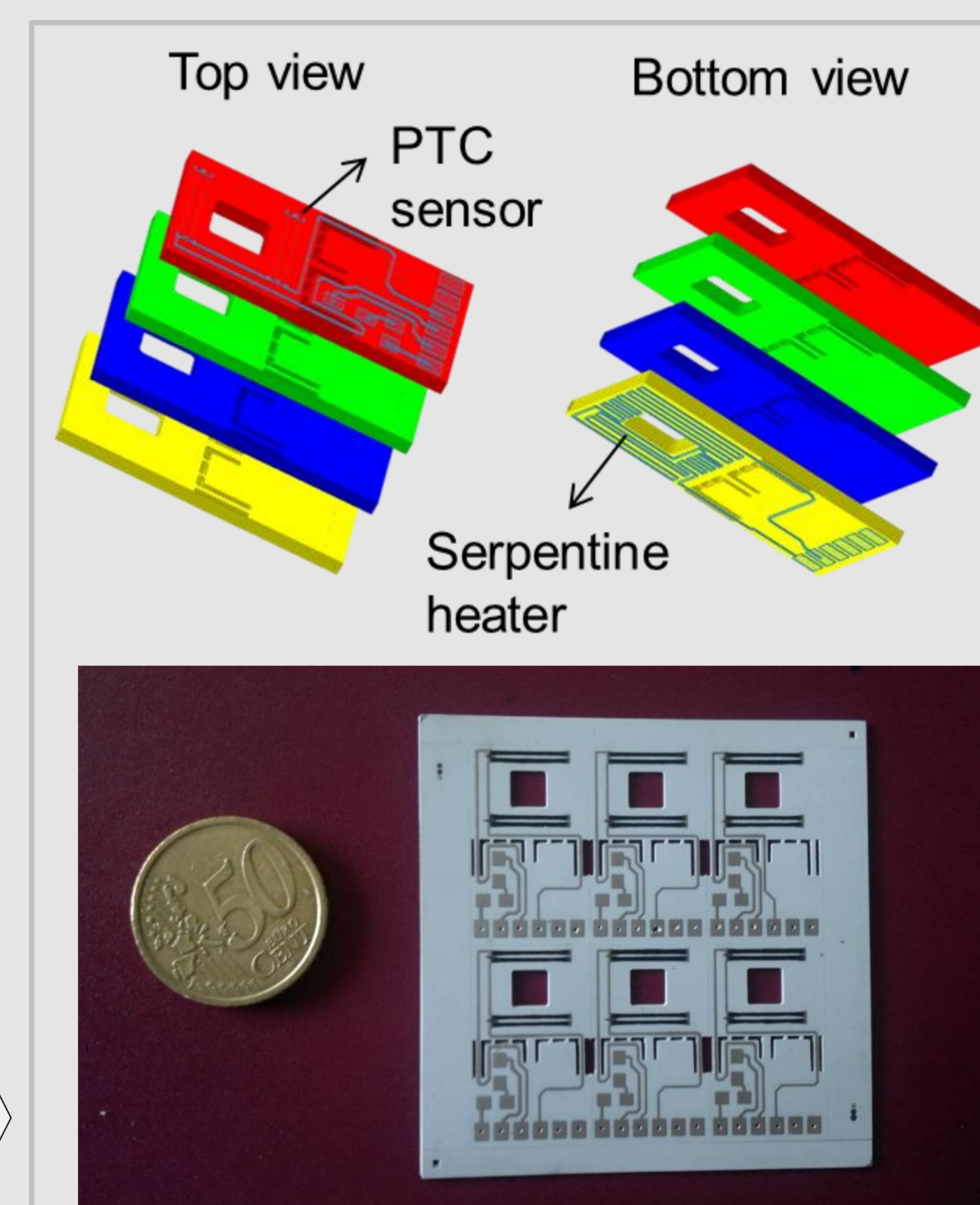
**Rb light source (10x10x3 mm<sup>3</sup>) fabrication process:** Hermetic sealing of Rb and buffer gas (Argon here) in a 5 mm diameter, 2 mm high cavity through a 2-step anodic bonding process



Microfabricated Rb DBD light source with stable optical power emission recorded up to 280  $\mu$ W on the Rb D2 line

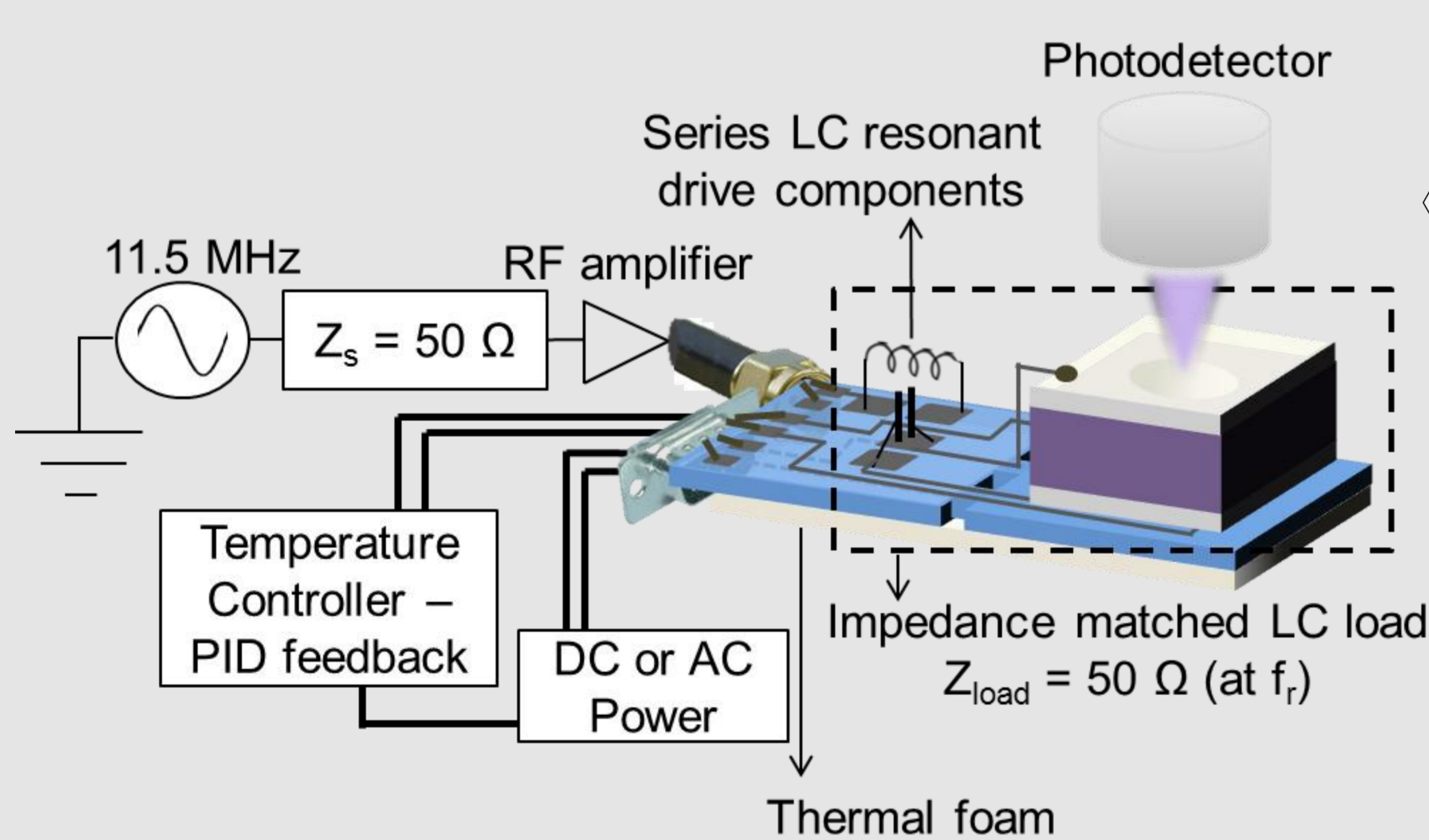


LTCC Heater and drive circuit platform with a heating capacity up to several hundred  $^{\circ}$ C and reduced thermal losses



**Fabrication of the LTCC heater and drive platform:** Vertical stacking and LTCC integration of 4 layers: top layer with a PTC sensor, bottom layer with a serpentine heater and two intermediate layers for robustness

## MODULE OPERATION AND RESULTS

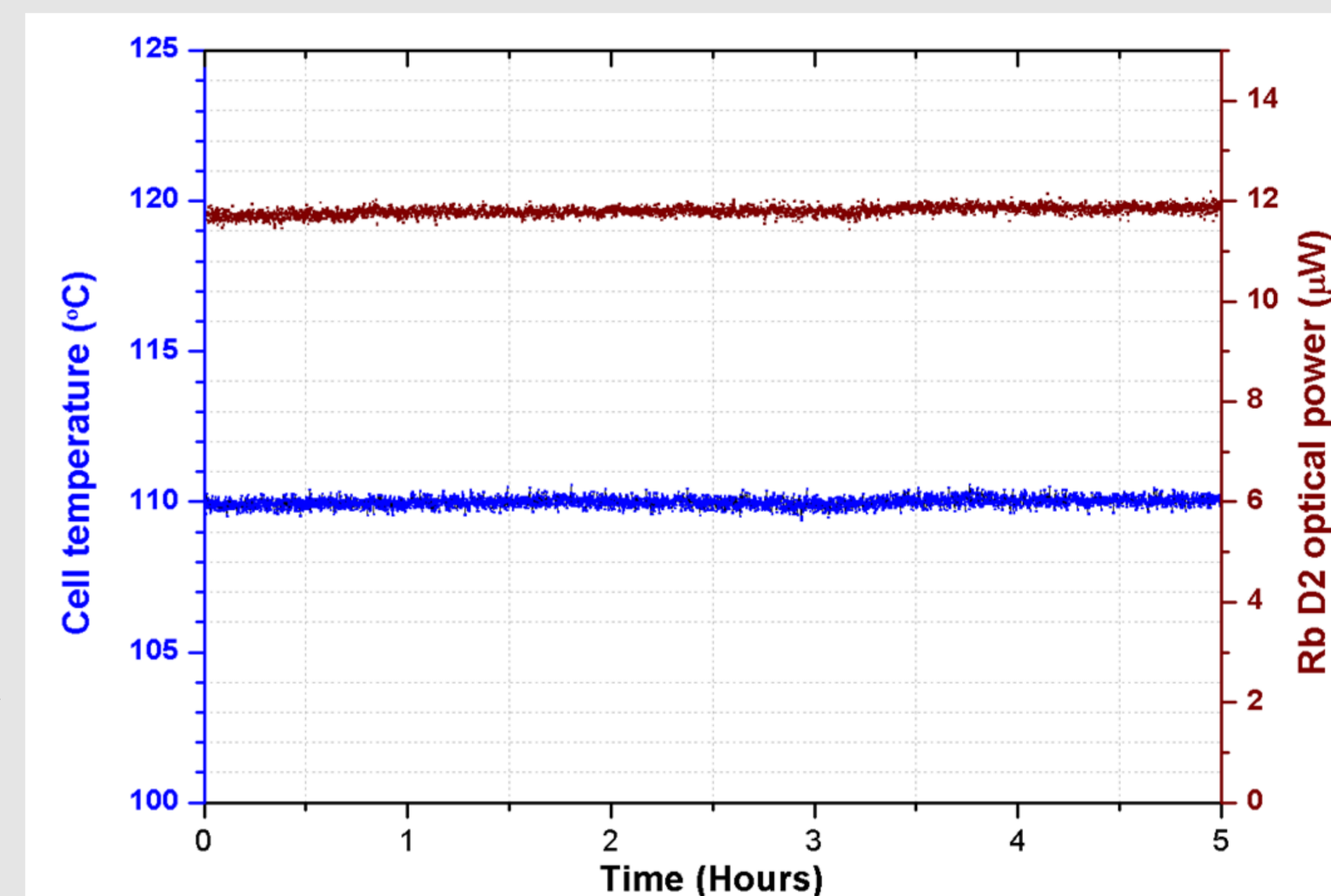


A series L-C resonant 50  $\Omega$  impedance-matching voltage amplification circuit was developed for maximum power transfer to the Rb DBD cell at the series resonant frequency while being highly space efficient.

The heater can be DC or AC powered and is temperature controlled using PID feedback.

The cell temperature and Rb D2 optical power measured from the module during a continuous run of 5 hours.

The lamp drive frequency here is 25 MHz with a forward power of 1.1 Watts and the heater is temperature controlled and operated at 7.1 V, 0.2 A DC.



## DISCUSSION AND CONCLUSIONS

- ❖ A novel LTCC integrated Rb mini-lamp module was developed for stable optical pumping in miniature applications.
- ❖ All the drive electronics and the test setup externally used for measurements can be integrated into a single module with only one external power supply connector.
- ❖ The combination of ITO and Al electrodes allows for a high photon output from the light source for a given input power.
- ❖ The ideal operating frequency range of the DBD lamp has to be identified based on the discharge gap conditions where the electron oscillation amplitude is just below the discharge gap length.
- ❖ While changing the buffer gas in the DBD lamp has almost no effect on the stability of the discharges, the power required for breakdown can be reduced by changing to other inert gases like Neon or a mixture of buffer gases.
- ❖ It is also possible to individually temperature control the L-C components by having dedicated heaters and temperature controllers for each L-C component to achieve a high LC series resonant quality factor and minimize the rf reflected power.

## REFERENCES

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- F. Vecchio, T. Maeder, C. Slater and P. Ryser, "Effects of thermal losses on the heating of a multifunctional LTCC module for atomic clock packaging", Solid State Phenom., vol. 188, pp. 244-249, 2012.