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Passive Thermal Control for an Infrastructure-Free Diagnostic Cassette

GÜDER RESEARCH GROUP, IMPERIAL COLLEGE LONDON · JUNE 2026 – AUGUST 2026

REQUIREMENT	POWER BUDGET	OPERATOR INPUT	COST TARGET
37–42 °C held for 20 minutes	**Zero external power**	**One water activation step**	**Single-use disposable**

PROBLEM

Isothermal DNA amplification is far more sensitive than a lateral flow assay alone, but it requires holding a reaction at elevated temperature for roughly twenty minutes, which normally means a heater, a controller, and a power source. That equipment is exactly what a point-of-care test is meant to eliminate. The design problem was to deliver a controlled thermal profile and a timed fluid transfer using only stored chemical energy and material properties, inside a disposable that a non-technical user activates with water.

ARCHITECTURE

The cassette is a two-stage passive system. An annular heating chamber wraps concentrically around the central sample chamber, maximizing heated wall area in contact with the reaction volume and keeping the thermal path short and radially symmetric. The sample chamber sits directly upstream of the lateral flow strip, separated from it by a sacrificial membrane that governs when amplified product is released.

1. **Exothermic charge.** Water activation triggers an $MgCl_2$ hydration exotherm: high energy density and fast release, but an uncontrolled spike on its own.
2. **PCM buffer.** A phase-change ring absorbs the exotherm peak as latent heat, then returns it slowly on crystallization, converting a spike into a usable plateau.
3. **Sacrificial valve.** A PVA membrane swells and ruptures on a fixed timescale, releasing product to the strip only after amplification completes.

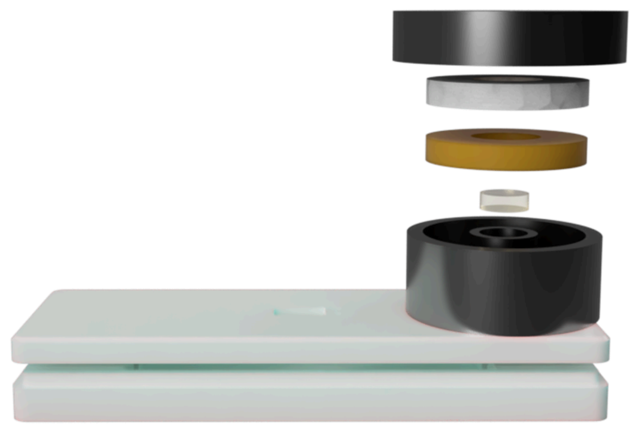

Fig. 1. Exploded assembly. Heating chamber, PCM ring and sample well stack concentrically above the lateral flow housing.

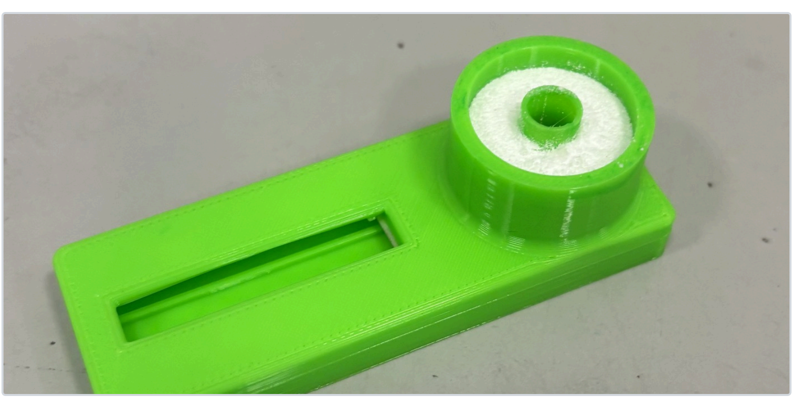

Fig. 2. Printed cassette body. The annular heating chamber (salt and phase-change material) surrounds the central sample well. The traditional lateral flow assay lies below the heating chamber, allowing gravity to pull the sample into the pad once the sacrificial membrane ruptures.

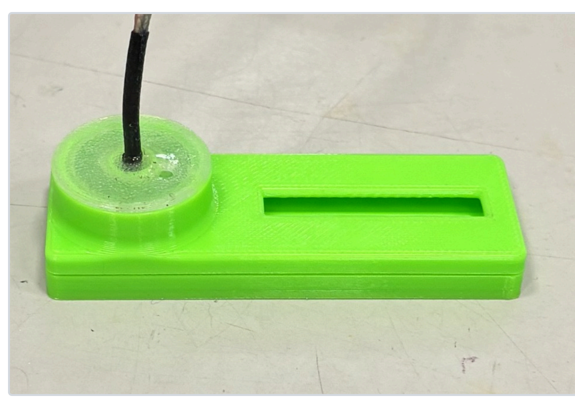

Fig. 3. Characterization build: a thermocouple sealed into the sample well logs reaction-volume temperature rather than chamber wall temperature.

DESIGN	FABRICATION	INSTRUMENTATION	ANALYSIS
Fusion 360	**FDM printing, membrane casting**	**Thermocouple logging**	**Python, Matplotlib**

THERMAL CHARACTERIZATION

The PCM and salt trade against each other: more $MgCl_2$ raises peak temperature and shortens the useful window, while more PCM flattens the peak but can absorb so much energy the volume never reaches temperature. Neither tunes independently, so I swept both across 49 combinations, logging a thermocouple sealed in the sample well on every run.

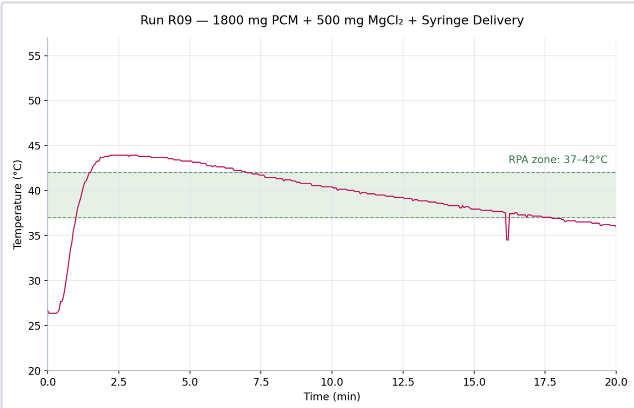

Fig. 4. Best configuration (R09, 1800 mg PCM / 500 mg $MgCl_2$). The charge drives the volume into the window within a minute; the PCM then holds it there as it crystallizes.

RESULT

Best configuration held the reaction volume in the 37–42 °C window for **~11 min** with no electrical input, and delivered product to the strip on a timescale set entirely by membrane geometry.

PCM mg \ MgCl2 mg	250	300	350	400	450	500	550
1000	0.80	1.10	0.90	1.50	1.80	1.90	1.90
1200	0.40	0.90	2.50	3.40	4.60	4.00	2.60
1400	0.70	1.30	2.90	4.60	6.90	6.10	5.00
1600	0.80	1.60	2.40	4.60	7.97	9.53	8.60
1800	1.10	1.50	2.10	3.90	7.93	11.13	10.47
2000	1.10	1.50	1.30	2.40	5.70	8.90	9.90
2200	0.60	1.20	0.80	1.70	3.20	5.00	6.30

Fig. 5. Minutes within the 37–42 °C window across the full 7 × 7 sweep. Performance is non-monotonic in both parameters. The optimum sits on a narrow ridge near 1800 / 500 and falls off sharply either side, so the operating point had to be found empirically.

PASSIVE TIMING VALVE

Product must not reach the strip early, because flow before amplification completes destroys the sensitivity gain the heater exists to produce. With no power available, timing had to be a material property, so I used a PVA membrane sized to swell and rupture at the end of the window. Casting condition sets both rupture time and how cleanly the membrane fails, so I screened PVA concentration (w/v), cast volume, and plasticizer additions by running a tracer dye on real LFA sample pads, so each run reported both *when* the membrane opened and *how*.

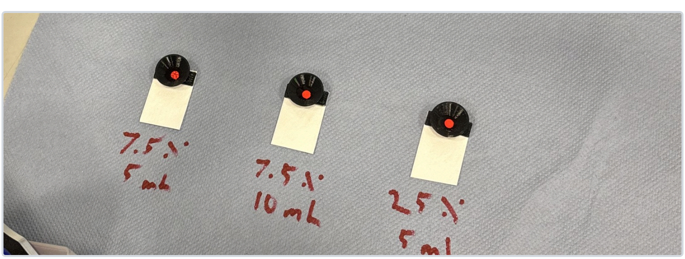

Fig. 6. Mid-test, before breakthrough. Dye fully retained, pads dry. Units labeled in frame by casting condition (PVA w/v %, cast volume).

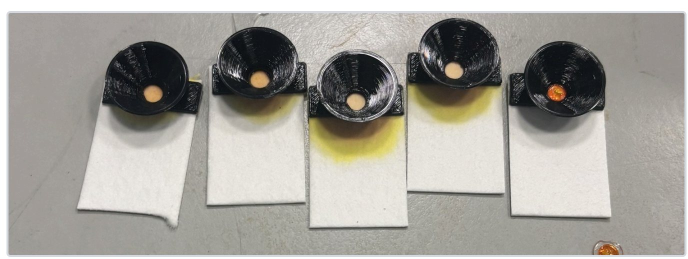

Fig. 7. After breakthrough. Dye front on the pad distinguishes clean release (center) from partial rupture; parallel units exposed build-to-build timing scatter.

ASSAY VALIDATION

With both subsystems characterized, I ran a limited end-to-end trial amplifying the *mecA* resistance gene from MRSA inside the cassette, confirming product by gel electrophoresis. The summer ended before I could repeat it at the replicate count a sensitivity claim would need, so it stands as proof of function rather than a performance number.