1: Dependence of metal (Al) thickness on $\Delta F$

We simulated the dependence of the LC resonant metal (aluminum/Al) thickness on $\Delta F$. According to skin depth calculations, the skin depth of Al at 1THz is 98nm. Regarding the effect of the thickness of metal in metallic resonators, sub-skin-depth thicknesses have a high resistance, such that the characteristic resonances are damped and eventually become extinct. The resonance at the skin depth has the best plasmonic effect, which gradually decays down with increasing metal thickness. Hence, when we simulated our arrowhead LC resonant metamaterial structure with 100nm$^2$ QDs as a dielectric with a low particle concentration at sub-skin depth thicknesses (<90 nm), the resonance is largely damped, resulting in decreased $\Delta F$. The $\Delta F$ is maximal just after the skin depth thickness (~100 nm), indicating the maximal plasmonic effect. Gradually, upon increasing the Al thickness up to 220 nm (which is much larger than the nanoparticles' diameter), the volume-fill factor of the dielectric decreased, which showed as a gradual decrease in $\Delta F$, which then reached a stable region.

![Figure S1](image-url)

**Figure S1.** Simulation of dependence of LC resonant metal (Al) thickness on $\Delta F$ showing the stable $\Delta F$ region and the chosen Al thickness for subsequent fabrication.
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This stable $\Delta F$ region is of the utmost importance to us, because if we keep our fabricated metal thickness around 200nm, any small error in deposition resulting in uneven metal thickness would not create a major impact on the $\Delta F$ of the chip during the breathalyzer test.

2: Minimizing Fabry-Perot oscillations using the capsule (radome)

In the Fabry-Perot phenomenon of Si substrate in the THz range, multiple beam interferences arise when the THz source shines on one surface of the Si, which causes periodic maxima and minima in the transmission mode. The periodicity of these maxima and minima is highly dependent on the thickness of the Si substrate used. Our CST simulations accurately predict the Fabry-Perot oscillations in the transmission mode for a Si substrate of thicknesses 725 µm and 500 µm.

![Figure S2. Simulation of dependence of THz transmission spectra on the Si substrate thickness. The period of the Fabry-Perot oscillations increases with an increase in Si thickness.](image)

Introducing a capsule which should act as a radome for the THz transmission induces significant changes of the transmission spectrum of our cross-arrowhead LC resonant metamaterial chip. Hence, we parametrically deduce the best geometric parameters for the front and back wall thicknesses of the capsule. We also take the material of the radome into consideration, because the dielectric of the capsule walls also induces significant changes in the transmission spectra. This parametric deduction is based on the concept of impedance matching in 2-port networks, where we ensure zero transmission loss due to the introduction of the capsule housing for the metamaterial chip. Figure S3 shows the transmission spectra of our arrowhead LC resonant metamaterial chip, where we can observe zero transmission loss due to the capsule. Moreover, the capsule has smoothed out the Fabry-Perot oscillations in the resonance region, and has attenuated the resonance signal by only -2.8dB, making the resonance dip more prominent.
3: Fabrication methods and working prototype

Four arrowhead metamaterial patterns for sensing low-density viruses/nanoparticles were prepared by e-beam evaporation and standard lithography on a Si substrate of t725 μm thick on an 8-inch wafer. A 200 nm Al film was deposited by e-beam evaporation to define arrays of electrical arrowhead resonators with a line width of 4μm, outer dimensions of 36μm × 36μm, and a capacitor gap of 1.5μm. The pitch between the elements was 50μm. 8mm dies were put into an enclosed capsule with a mouthpiece that will aid the patient to exhale air onto the metamaterial chip, as shown in Figure 1(b-f) (see main article). Figure S4 shows a microscopic image of our fabricated four arrowhead LC resonant metamaterial patterns. Once a patient blows onto the chip surface via the breathalyzer mouthpiece (with proper air flow design), the mouthpiece is removed and the chip is covered with the capsule lid. The capsule is then externally disinfected in alcohol for 3 minutes and placed on the THz spectrometer holder between the transmitter and receiver to capture the transmittance spectra. The obtained transmittance spectrum is further analyzed at the resonance region and the relative change in resonance frequency (ΔF) between the reference and the sample (measurement) is calculated using Gaussian fitting.

Figure S5 shows a snapshot of our breathalyzer-based coronavirus carrier testing kit and the experimental setup to capture the transmittance spectra. As the beam-width of the THz spectrometer from the parabolic mirror is about 12mm in radius, we placed an iris of the same size as the arrowhead resonant chip active area (6x6mm) at the FWHM of the incident Gaussian beam. The semi-transparent capsule is...
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used directly for THz spectrometric scanning with the lid securely fastened in an air-tight manner, according to the specifications in the CST simulations performed.

Figure S4. Microscopic image of the fabricated arrowhead LC resonant metamaterial structure on Si chip.

Figure S5. (a) Snapshot of our breathalyzer testing kit consisting of the mouthpiece (blower), capsule and in-house fabricated LC resonant metamaterial chips; (b) snapshot of open capsule cover revealing chip inside the capsule; (c) snapshot of the entire breathalyzer kit assembly ready to be exhaled into; and (d) THz scanning system showing the capsule mounted on a holder placed between transmitter and receiver to scan in transmission mode.
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4: Air flow design

Air-flow designing was conducted to ensure gradual deposition of the particles exhaled by an individual onto the chip. The design of the nozzle and the capsule is such that when an individual blows air from the mouth onto the chip via the nozzle, the thrust of the exhaled air exits from little vents on the sides of the nozzle, so that the particles exiting the individual's mouth settle on the chip, instead of flying away. The figure below schematically sketches the air flow mechanism.

Figure S6. (a-c) Step by step schematic sketch of the air flow mechanism. (a) After the individual blows onto the chip, via the nozzle (b), the thrust of the exhaled air exits from little vents on the sides of the nozzle, as shown with blue arrows (c), so that the particles exiting the individual's mouth settle on the chip instead of flying away.

5: Information about THz spectrometer used

We used a linearly polarized Toptica Systems TeraScan 1550 to record the transmittance spectra. This spectrometer has an InGaAs photo-mixer with a metal-insulator-metal heterostructure architecture. The photo-mixers use distributed laser feedback (DFB) technology to unite two temperature-controlled 1.5um lasers with a minute difference in wavelength and obtain the envelope of the interference spectrum, termed the ‘laser beat’, which is in the THz domain\(^1\). This spectrometer works with a coherent detection scheme, where the second photo-mixer acts as the THz receiver. The incoming THz wave generates a voltage in the antenna, while the ‘laser beat’ modulates the conductivity of the photomixer\(^1\). The resulting photocurrent (which is the unit of the output spectra) is proportional to the amplitude of the THz electric field\(^1\). The entire setup is controlled by a microcontroller unit (MCU) based on a FPGA with an internal clock rate of 130MHz to facilitate different programming operations\(^1\). Figure S7 shows our entire THz scanning setup for screening coronavirus carriers.
**6: Correlation of the $\Delta F$ data of the clinical trials with the simulation results**

To correlate the data from the clinical trials with the simulation results, we compared the $\Delta F$ values of the trials with the CST simulation results. The $\Delta F$ of patients with varying levels of CT values were compared to the $\Delta F$ obtained by varying the surface density of deposited nanoparticles with relative permittivity identical to that of a biological cell$^{2,3}$. Since the exhaled particles of an infected patient mainly consist of viruses and other biological debris, this correlation gives an insight into the effect of particle concentration on $\Delta F$, from a simulative (Figure S8(a)) and an experimental (Figure S8(b)) perspective. The $\Delta F$ characteristics upon variation of the viral load and the nano-cytoplasm-like entity are identical, and we observe a proportionality between the concentration of the virus load and the $\Delta F$ (Figure S8(b)), similar to the $\Delta F$ characteristics of the increasing concentration of nanoparticles shown in Figure S8(a).
We can also intuitively extrapolate the approximate viral load by comparing the experimentally obtained $\Delta F$ with the simulation results in the future.

Figure S8. Comparison of $\Delta F$ values obtained in the (a) simulation results with respect to varying surface density of deposited 100nm diameter sized particles with relative permittivity identical to that of a biological cell, with the (b) clinical trials (without the incorrectly predicted samples) with respect to varying viral load (CT of the PCR).

7: Automation procedure for $\Delta F$ extraction

In the process of automating the breathalyzer test for coronavirus carriers, we developed a unique spectrum processing technique, where the raw THz spectrum from the spectrometer is fed into an algorithm intended to calculate $\Delta F$ with decimal point accuracy. The raw spectrum is analyzed in the resonance region, where three separate standard mathematical tools (i.e. local and global minima computations, weighted mean computations and Hilbert envelope derivation) for spectrometric calculations are used to fit a Gaussian curve to the raw spectrum. To keep the analysis robust, an intelligent mathematical algorithm works on top of these, to determine the accurate $\Delta F$, correct to one decimal point. All the statistical results shown in Figure 4 in the main paper are computed by the above method.

Typically, the resonance region of each sample in the transmission spectrum is characterized by a Gaussian dip deterministically different from the standard Si Fabry-Perot dip. This occurs when the transmitted THz wave is tuned perfectly to the natural resonance frequency of the LC resonant metamaterial structure and the entire resonant THz wave gets reflected back instead of being transmitted. For each of the clinical trial samples we Gaussian fitted the resonance regions of both the measured spectrum (after blowing into the capsule) and the reference spectrum. Then we computed $\Delta F$ by
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subtracting the minima of both the Gaussian fitted spectra ($\Delta F_{\text{GaussianFitMinima Reference}} - \Delta F_{\text{GaussianFitMinima Measurement}}$).

In our broad range of clinical trials, we encountered many noisy spectra. Some spectra have a broadened resonance region, with noise in the resonance dip itself. Some samples have a wavy nature owing to the Fabry-Perot oscillations between the metamaterial chip and the capsule. Most prominently, we experience inconsistent resonance frequencies over chips fabricated on the same mask design. The chip-to-chip variation of resonance frequency ranges up to 10GHz, making it absolutely necessary to calculate $\Delta F$ with decimal point accuracy. Therefore, instead of using the spectrometer-calculated envelope (which is done by averaging the photocurrent), we generate our own envelope by taking the average of local minima and local maxima of the sinusoidal photocurrent of the raw spectrum. The assimilation of the above algorithms is inlayed into a smart automation software package that analyzes $\Delta F$ right after the scanning and displays whether the individual is positive or negative within a minute.

8: Low scale verification clinical trial dataset

In this section we show the entire forty dataset details, with their corresponding sample number, $\Delta F$, our prediction, RT-qPCR results, CT values, and the remarks indicating whether the sample was true positive / true negative / false positive / false negative.

Table S1. Low scale verification clinical trial dataset

| Sl. No. | Sample No. | $\Delta F$ (GHz) | Prediction | RT-qPCR Results | CT   | Remarks           |
|---------|-------------|------------------|------------|-----------------|------|------------------|
| 1       | 2345        | 4.1              | POSITIVE   | POSITIVE        | 30   | True Positive    |
| 2       | 2346        | 9.2              | POSITIVE   | POSITIVE        | 21   | True Positive    |
| 3       | 2353        | 2.1              | POSITIVE   | POSITIVE        | 29.88| True Positive    |
| 4       | 2355        | 2.11             | POSITIVE   | POSITIVE        | 37.14| True Positive    |
| 5       | 2357        | 1.99             | POSITIVE   | POSITIVE        | 34.45| True Positive    |
| 6       | 2360        | 2.5              | POSITIVE   | POSITIVE        | 36.19| True Positive    |
| 7       | 2177        | 3.02             | POSITIVE   | POSITIVE        | 35.69| True Positive    |
| 8       | 2197        | 3.3              | POSITIVE   | POSITIVE        | 36.4 | True Positive    |
| 9       | 2198        | 2.3              | POSITIVE   | POSITIVE(next day) | 37.31| True Positive    |
| 10      | 2199        | 2.1              | POSITIVE   | POSITIVE        | 31.01| True Positive    |
| 11      | 2341        | 1.6              | POSITIVE   | POSITIVE        | 27.84| True Positive    |
| 12      | 2343        | 2.7              | POSITIVE   | POSITIVE        | 29.62| True Positive    |
| 13      | 2344        | 2.8              | POSITIVE   | POSITIVE        | 29   | True Positive    |
| 14      | 2348        | -0.5             | NEGATIVE   | POSITIVE        | 22   | False Negative   |
| 15      | 2342        | 0.34             | NEGATIVE   | POSITIVE        | 25.95| False Negative   |
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|   | 2349   |  -1  | NEGATIVE | POSITIVE | 28       | False Negative |
|---|--------|------|----------|----------|----------|----------------|
|17| 2347   |  -0.4| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|18| 2352   |  -0.4| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|19| 2358   |   0.3| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|20| 2191   |  0.75| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|21| 2192   |  0.7 | NEGATIVE | NEGATIVE | N.A.    | True Negative |
|22| 2193   | -0.56| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|23| 2194   |  0.94| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|24| 2195   |  0.54| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|25| 2196   | -0.93| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|26| 2178   |  0.29| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|27| 2208   | -0.9 | NEGATIVE | NEGATIVE | N.A.    | True Negative |
|28| 2214   |  0.96| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|29| 2252   |  1.02| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|30| 2253   |  0.78| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|31| 2287   | -0.02| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|32| 2288   |   0.8| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|33| 2292   |  0.22| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|34| 2294   |  0.96| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|35| 2298   |  0.28| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|36| 2300   |  0.55| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|37| 2200   |  1.34| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|38| 2304   |  0.67| NEGATIVE | NEGATIVE | N.A.    | True Negative |
|39| 2285   |   3.9|  POSITIVE | NEGATIVE | N.A.    | False Positive |
|40| 2176   |  4.932|  POSITIVE | NEGATIVE | N.A.    | False Positive |

ΔF: resonance frequency shift, RT-qPCR: real-time quantitative polymerase chain reaction, CT: cycle threshold, N.A.: not applicable

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