Supplemental Material

DESIGN OF NONLINEAR METASTRUCTURE FOR TEMPERATURE DETECTION AND BIOSENSING BASED ON SECOND HARMONIC GENERATION

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1. The fabrication of nonlinear Metastructure (NM) devices.

The layered structure proposed in this study is a theoretical design that pursues theoretical effects and does not pay too much attention to manufacturing. Then, if specific manufacturing is required, it can be done as follows: In the fabrication process, an etching technique is utilized. Initially, two periodically poled lithium niobate crystals (LNC) crystals with a period of *N* are prepared at room temperature using electrode polarization. Standard optical-grade Z-cut LNC, with a thickness of approximately 0.5 mm, are employed [1]. This thickness is significantly greater than the designed structure length, thus ensuring free extension in height or width, and can be considered an ideal structure. The detailed procedure is illustrated in Fig. (S1). In the first step, a thin layer of photoresist is deposited on the surface of the LNC. In the second step, the designed periodic lattice (determining the thickness of layers A and B) is patterned onto the photoresist through photolithography. The third step involves contacting the exposed regions with a liquid electrolyte (saturated lithium chloride solution in deionized water) and separating the unexposed parts. In the fourth step, an electrode plate is deposited on the sample surface, followed by applying a pulsed electric field of approximately 20 kV/mm² across the crystal, inducing periodic poling [2]. The poling process typically progresses from the growth of ferroelectric domains to their expansion and eventual formation. Ultimately, two periodically poled LNC samples are obtained. In Fig.S1, the different directions of the red arrows indicate the reversal of the LNC ferroelectric domains, specifically marked as A and B to denote the regions with opposite polarization directions [3]. Additionally, as shown in Fig.(S1f), when applying periodic poling to LNC, an air layer thickness must be reserved. After the poling process is complete, the unpoled portions of LNC are etched away using an etchant.

In the fifth step, LNC is chosen as the substrate. A groove with the designed thickness of the test layer (T) is etched into the silicon wafer using wet etching in advance. Finally, the two periodically poled LNC crystal parts and the T layer are assembled. The analyte is then injected into the measurement layer using a vacuum pipette, resulting in a complete NM sample. The specific fabrication process flow of our proposed layered structure be found in Figs.S1(a)-(g).

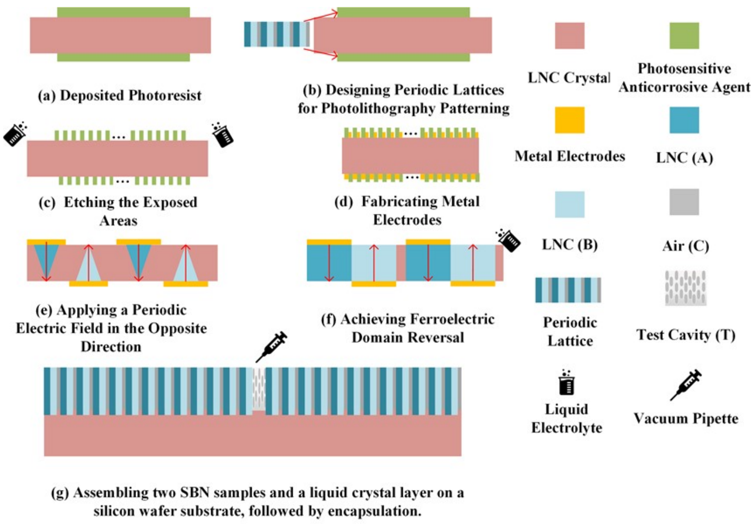

Fig.S1. The design and fabrication process of the NM. (a) and (b) depict the periodically poled lattice, representing the thickness and period of layers A and B in the NM structure as designed in the main text, achieved through photolithography on the surface of LNC. (c) Typically requires deposition in the electrolyte solution for over 10 minutes. (e) and (f) capture a small portion of (d), demonstrating the ferroelectric domain growth of the LNC under the influence of an electric field. (g) A groove for the test layer and the air layer thickness is pre-etched into the LNC substrate. The two samples are then assembled together [4].

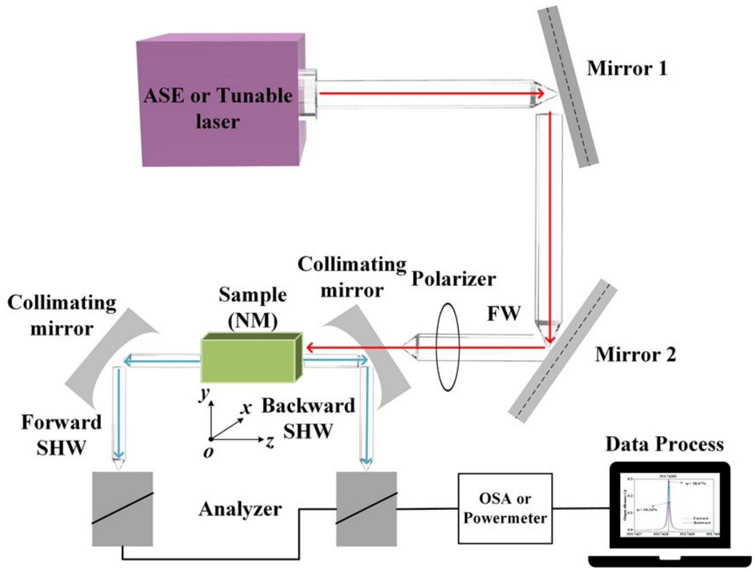

Fig. S2. The experimental setup for second harmonic generation [6].

The tunable optical parametric oscillator, typically pumped by an Ti: Sapphire femtosecond laser [1], is employed to measure the SHW conversion efficiency of MJMS samples. It generates a fundamental wavelength at 850nm-1450nm, with a maximum pump power of approximately 0.1 GW/cm^2, well surpassing the requirements of this study [2]. The pulse width of 350 fs effectively minimizes the medium's SHW loss to a negligible level. Fig. S2 illustrates the experimental setup for the generation and collection of SHW signals. The SHW signal collection includes both forward and backward signals. The laser, generating a fundamental wave at frequency ω, is adjusted by a collimator before being directed into the sample, allowing for the optimal coupling of the fundamental wave into the sample. In this study, the laser can be continuously tuned within the range of 1245 nm - 1250 nm, inducing frequency or amplitude shifts in the SHW signal. The analysis layer serves to filter out excitation light, fluorescence, and potential background light, ensuring the precise collection of SHW signals. Polarizers are employed to selectively filter TE and TM light. The SHW signal, after passing through the analysis layer, is detected using a photomultiplier tube [5]. Finally, signal collection, storage, and analysis are carried out using a computer and a power meter.

Certainly, the practical implementation of the proposed NM faces critical challenges, particularly the need for a laser source with broader continuous tunability to achieve optimal phase matching across operational parameters. Additionally, structural imperfections arising from insufficient chemical etching during fabrication may cause non-uniform thickness distribution in NM components, leading to degraded SHW generation efficiency due to disrupted phase-matching conditions. These technical constraints currently impact the device's performance consistency and scalability, highlighting the need for improved fabrication protocols, alternative high-precision lithography techniques, and design optimizations to accommodate reasonable fabrication tolerances in future work.

Reference

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