Supporting Information

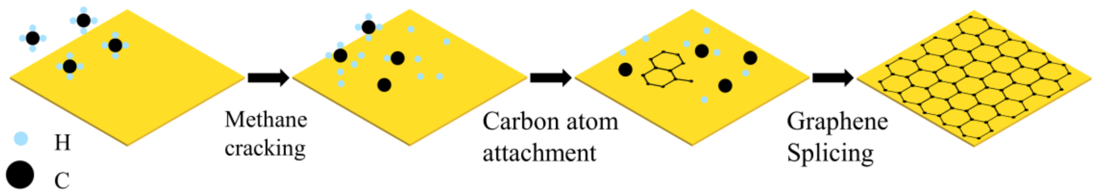

Figure S1 Schematic diagram of graphene growth by CVD

The preparation of graphene using the CVD method can be divided into five stages:

Stage 1: The gaseous carbon source is cleaved into active carbon atoms and hydrogen atoms dispersed in the gas under high temperature as well as copper catalysis.

Stage 2: The cleavage produces active carbon atoms that are adsorbed by the copper substrate and deposited on the surface of the copper substrate.

Stage 3: The deposited carbon atoms will diffuse on the surface of the copper substrate and polymerize at high-energy sites on the surface of the copper substrate, typically at grain boundaries or impurities, to become nucleation sites for graphene.

Stage 4: With the nucleation site of graphene as the center, graphene slowly grows in all directions, expanding the size of graphene.

Stage 5: The grown graphene gradually splices into a complete piece of graphene, until it completely covers the copper substrate.

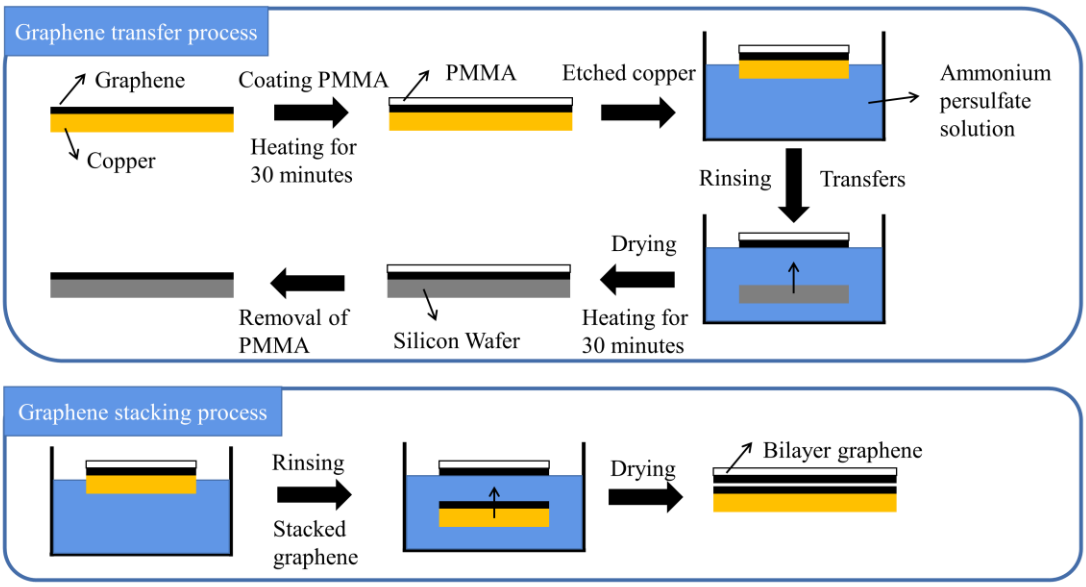

Figure S2 Schematic diagram of graphene transfer process

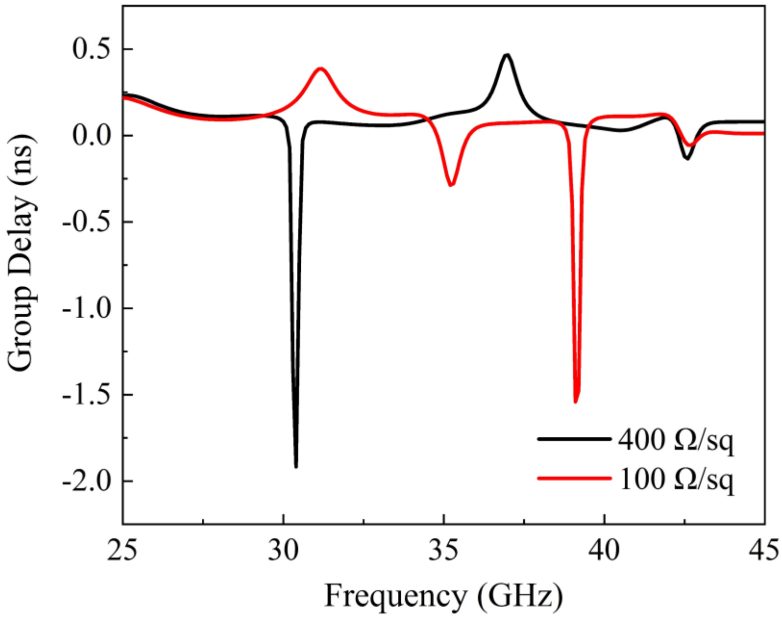

Figure S3 Antenna group delay

The group delay of antenna which working in different modes is shown in Figure S3. When the impedance of graphene is 400 Ω/sq, the group delay of the antenna reaches a maximum of -1.92ns out of 30.4GHz. When the impedance of graphene is 100 Ω/sq, the group delay of the antenna reaches a maximum of -1.54ns out of 39.1GHz.

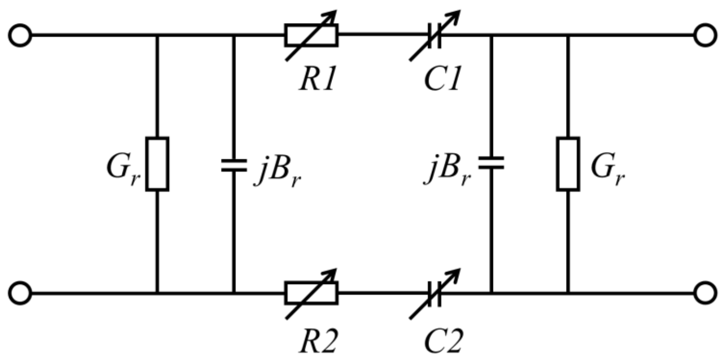

Figure S4 Antenna equivalent circuit model

The equivalent circuit model of the antenna is shown in Figure S4. The designed frequency reconfigurable antenna is a rectangular microstrip patch antenna. According to the transmission line model, the rectangular patch can be equated as two slots with complex conductance $Y=G_r+jB_r$ at a distance of L1 from each other. between these two equivalent slots is an equivalent transmission line with characteristic impedance Y_c. Since the rectangular graphene film is added to the patch of the designed antenna, the characteristic impedance Y_c of the transmission line is different from the traditional transmission line characteristic impedance calculation method, and the impedance of the graphene film and the patch should be considered comprehensively.

The input admittance Y_{in} of the antenna can be expressed by the Equation (S1):

$$Y_{in} = Y + Y_c \frac{Y + jY_c \tan \beta L1}{Y_c + jY \tan \beta L1} \qquad \text{(S1)}$$

The Yc in the Equation (S1) indicates a comprehensive consideration of the characteristic impedance of the graphene film and the patch. Since the graphene conductivity is adjustable, the Yc is variable, causing the input conductance Yi_n of the antenna to change, resulting in the change of the resonant frequency of the antenna to achieve the purpose of frequency reconfigurability.

where G_r can be calculated by the Equation (S2):

$$G_r = \begin{cases} \frac{1}{90}\left(\frac{w}{\lambda}\right)^2, w < 0.35\lambda \\ \frac{1}{120}\frac{w}{\lambda} - \frac{1}{60\pi^2}, 0.35\lambda \le w < 2\lambda \\ \frac{1}{120}\frac{w}{\lambda}, 2\lambda \le w \end{cases} \qquad \text{(S2)}$$