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Effect of Built in Polarization on Thermal Properties of InGaN/GaN Heterostructures

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Abstract : An important feature of $In_xGa_{1-x}N$/GaN heterostructures is strong built-in polarization (BIP) electric field at the hetero-interface due to spontaneous (sp) and piezoelectric (pz) polarizations. The intensity of this electric field reaches several MV/cm. This field has profound impact on optical, electrical and thermal properties. In this work, the effect of BIP field on thermal conductivity of $In_xGa_{1-x}N$/GaN heterostructure has been investigated theoretically. The interaction between the elastic strain and built in electric field induces additional electric polarization. This additional polarization contributes to the elastic constant of $In_xGa_{1-x}N$ alloy. This in turn modifies material parameters of $In_xGa_{1-x}N$. The BIP mechanism enhances elastic constant, phonon velocity and Debye temperature and their bowing constants in $In_xGa_{1-x}N$ alloy. These enhanced thermal parameters increase phonon mean free path which boost thermal conduction process. The thermal conductivity (k) of InxGa1-xN alloy has been estimated for x=0, 0.1, 0.3 and 0.9. Computation finds that irrespective of In content, the room temperature k of $In_xGa_{1-x}N$/GaN heterostructure is enhanced by BIP mechanism. Our analysis shows that at a certain temperature both k with and without BIP show crossover. Below this temperature k with BIP field is lower than k without BIP; however, above this temperature k with BIP field is significantly contributed by BIP mechanism leading to k with BIP field become higher than k without BIP field. The crossover temperature is primary pyroelectric transition temperature. The pyroelectric transition temperature of $In_xGa_{1-x}N$ alloy has been predicted for different x. This signature of pyroelectric nature suggests that thermal conductivity can reveal pyroelectricity in $In_xGa_{1-x}N$ alloy. The composition dependent room temperature k for x=0.1 and 0.3 are in line with prior experimental studies. The result can be used to minimize the self-heating effect in $In_xGa_{1-x}N$/GaN heterostructures.

Keywords : built-in polarization, phonon relaxation time, thermal properties of $In_xGa_{1-x}N$ /GaN heterostructure, self-heating
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