ELECTRICAL, OPTICAL AND THZ EMISSION STUDIES OF GA$_X$IN$_{1-X}$AS BULK CRYSTALS

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ABSTRACT

The III–V alloy semiconductor $Ga_xIn_{1-x}As$ covers the mid–IR wavelength range between 0.85 μm and 3.4 μm and is suitable for optoelectronic devices such as laser diodes, photodetectors and thermo–photovoltaic cells. However, only few compositions of the $Ga_xIn_{1-x}As$ system have been extensively researched due to difficulty in growing bulk substrates. Mostly, these ternary compound device structures are fabricated in thin film form on binary substrates. For example, $Ga_{0.47}In_{0.53}As$ is being widely used for commercial photodiodes in fiber optic communication and $Ga_{0.47}In_{0.53}As$ lattice matched on InP laser is used in Infrared (IR) detection. Recently, III–V compound semiconductor material systems have received increased attention as potential practical sources of emission of THz electromagnetic radiation as GaAs, InAs, GaSb, InSb, and InP have demonstrated coherent emission of radiation upon irradiation with ultrafast laser pulses. In particular, InAs has demonstrated the highest emission of THz radiation of all semiconductor systems characterized to date. The contribution of THz radiation from InAs is attributed to a large photo–Dember electric field upon irradiation of the material's surface with ultrafast laser pulses that in turn drives sub–surface surge currents. Conversely, GaAs, a wide band gap semiconductor compared to InAs, has shown emission of THz radiation upon irradiation with ultrafast laser pulses dominated by a different physical phenomena. In GaAs, the dominant THz radiation mechanism is due to surface Fermi level pinning in the semiconductor that creates surface electric field. This leads to acceleration of charges resulting in THz emission. As a result, the III–V ternary alloy semiconductor $Ga_xIn_{1-x}As$ is an interesting THz research material system since it is expected to exhibit emission of radiation properties physically related to both binary systems InAs and GaAs.

The goal of the present research effort was to investigate the fundamental electrical and optical properties of $Ga_xIn_{1-x}As$ bulk crystals with alloy composition range between $0 < x < 0.65$. Our room temperature electrical analysis of undoped $Ga_xIn_{1-x}As$ ($0 < x < 0.65$) reveals mobility changes from 20,700 cm^2/Vs

for InAs to 3,320 cm^2/Vs for $Ga_{0.64}In_{0.36}As$. In addition, the THz emission mechanisms were studied as they relate to the semiconductor properties, such as mobility, carrier concentration, and energy bandgap. Our THz emission studies indicate that the photo–Dember effect is dominant for $Ga_xIn_{1-x}As$ with $0 < x < 0.1$ while the surface field effect is dominant for $Ga_xIn_{1-x}As$ with $0.1 < x < 0.64$. In addition, optical rectification, a second order nonlinear optical effect, which is also capable of generating THz radiation has been observed in $Ga_xIn_{1-x}As$. Furthermore, compensations studies via zinc diffusion at 535 ^{o}C have been performed on $Ga_xIn_{1-x}As$ bulk substrates for various alloy compositions with $0 < x < 0.7$. It has been found that zinc diffusion degrades the THz emission properties in $Ga_xIn_{1-x}As$ via reduced charge carrier mobility (due to ionized impurity scattering) and increase in free carrier absorption.