Fabrication and evaluation of polymer varactor diodes for sub-THz frequency band

NTT Dev. Tech. Labs[1], ◦Adam Pander[1], Satoshi Kawahara[1], Daisuke Kitayama[1], and Hiroyuki Takahashi[1]

E-mail: adam.pander.ec@hco.ntt.co.jp

A varactor diode is a relatively simple device usually composed of stacked p-type and n-type semiconductor films, possessing a large benefit of capacitance control in a response to a negative potential applied to one of the electrodes. Such type of diodes is commonly used in electronics tuners in various receivers, low noise amplifiers, frequency generators, adjustable bandpass filters, and in recent years also in various beamforming devices, like reconfigurable intelligent surfaces (RIS).

In some applications that involve multilayer structures, like multilayer beamformers or RIS in a sub-THz frequency band, the use of bulky inorganic semiconductor diodes proves to be difficult, or even impossible with the increase of operating frequencies. Also, typically used inorganic diodes, based on Si, GaN, GaAs, InP, etc, require fabrication on a native material substrate to allow for ion doping and p-n junction formation. To use such diodes in multilayer devices, or with different substrates, complex transfer techniques between wafers are necessary; however, with the increase of the elements per layer, even such transfer techniques become inefficient. One of the ways to alleviate these issues is the use of materials that can be directly fabricated on any type of base substrate or can be implemented into a multilayer structure with ease. Polymer-based devices offer various advantages, such as low-cost, lightweight, high flexibility, and large-scale processing possibility. Furthermore, in the sub-THz band, the polymer diodes can be directly fabricated on various substrates and multilayer structures, enabling the development of novel beamformer technologies. Also, since the dielectric constant of polymer materials is much lower than inorganic semiconductors, the insertion losses in the devices can be limited.

The purpose of this study is the fabrication and evaluation of electrical properties, including the variable capacitance, of polymer varactor diodes at sub-THz frequencies. In this work, p-type P3HT and n-type N2200 polymers are used with different types of solvents to allow for stacking p-type and n-type polymers. The diameter and the polymer film thickness of fabricated diodes were designed to exhibit femtofarad capacitance variation that could be usable in sub-THz bands.

In this study, Au/P3HT/N2200/Al varactor diodes were fabricated with different diameters ϕ = 2~20 μm (Fig. 1(a)). The voltage-current (V-I) characteristics of the diodes were measured (Fig. 1(b)) using a DC probe station. The capacitance of the diodes was extracted separately from S-parameter measurements (Fig. 1(c)) using a vector network analyzer (Keysight PNA-X) and WR3.4 frequency extender in the 220 – 325 GHz frequency band. To the extent of our knowledge, this is the first report of a polymer varactor diode in a J-band.

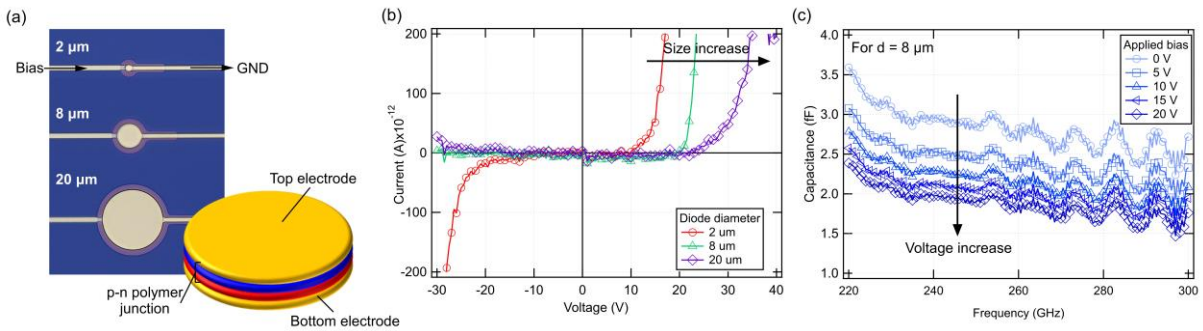

Figure 1. (a) Fabricated polymer varactor diodes with different diameter size and overall schematic. (b) The V-I characteristics of the polymer varactor diodes for d = 2, 8, and 20 μm. (c) Capacitance variation versus the applied bias voltage in the 220 – 325 GHz frequency band.