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BiCMOS devices under mechanical strain

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Due to increasing interest in strained-Si MOSFET with enhanced electron and hole mobility [1,2], the device mobility can be further improved by applying the mechanical strain properly. The physics for the external strain field on the unstrained and strained devices is not only important for the design guide but also can be applied for the device packaging. The mobility degradation due to the high-κ gate dielectrics can be relieved under the proper mechanical strain.

The strained-Si layers (20 nm-thick) were grown by UHVCVD on the relaxed $Si_{0.8}Ge_{0.2}$. The fabrication process of the strained-Si FETs can be found elsewhere [3]. To integrate the CMOS technology, high-κ HfO_2 used as a gate dielectric with the CET of ~4.8 nm for PMOS and NMOS devices was deposited on control Si substrate by sputtering system. The SiGe base of HBT grown by UHVCVD consists of an undoped Si layers (30-nm thick), SiGe graded layer (Ge=0-20%) with B of 10^{19} cm^{-3} and the undoped $Si_{0.8}Ge_{0.2}$ base layer (30-nm thick) [4]. The biaxial mechanical strain and the strain field distribution by the mechanical setup were described in [5]. The uniaxial strain is also investigated by a conventional one-end-bending method.

Fig. 1 shows the uniaxial strain effects on the I_{ds}-V_{ds} characteristics of control and strained-Si NMOSFETs. It is observed that uniaxial tensile strain parallel/perpendicular to the channel can enhance the I_{ds} of NMOS devices, while uniaxial tensile (compressive) strain perpendicular (parallel) to the channel can enhance the I_{ds} of PMOS devices. The biaxial tensile strain can also enhance the I_{ds} of the control Si NMOS devices with HfO_2 gate oxides, while the PMOS has a reduced current after the same biaxial strain (Fig. 2). The I_{ds} enhancement of HfO_2 gate dielectric is slightly higher than the SiO_2 NMOS devices. It is known that mobility can be degraded with the HfO_2 gated MOSFET devices but it can be improved by applying the mechanical strain. The hole mobility (Fig. 3) of control Si and strained-Si PMOS can be further improved with the uniaxial tensile strain perpendicular to the channel. The electron (Fig. 3) and hole mobility of strained-Si devices are increased with the biaxial tensile strain. The electron mobility of control Si is improved but the hole mobility decreases after the biaxial tensile strain due to the higher effective mass and the abnormal behavior of hole mobility at the small strain. The compressive strain improves the I_C and β of SiGe HBT/Si BJT devices (Fig. 4) due to the combine effects of mobility and the intrinsic carrier concentration under the mechanical strain. In conclusion, the mobility and current gain can be enhanced by properly applying the mechanical strain on the particular devices. This simple mechanical strain effects on the BiCMOS can give a new research direction and layout design for the Si-based heterostructure device applications.

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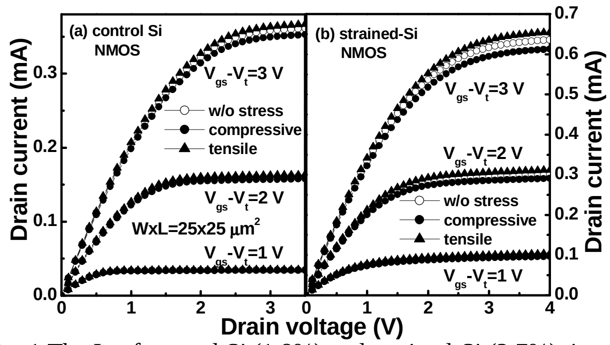

Fig. 1 The I_{ds} of control Si (1.8%) and strained-Si (2.7%) increases with the tensile strain (~0.097%) parallel to the channel of NMOS devices, while the I_{ds} of control Si (-2.5%) and strained-Si (-3.3%) decreases with the compressive strain at V_{ds}=1V and V_{gs}-V_t=3V.

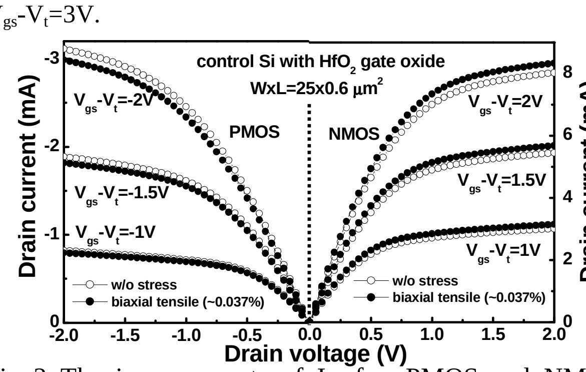

Fig. 2 The improvements of I_{ds} for PMOS and NMOS devices with HfO_2 gate dielectrics are found to be –4.8% and 4.9%, respectively, at V_{ds}=1V and V_{gs}-V_t=2V.

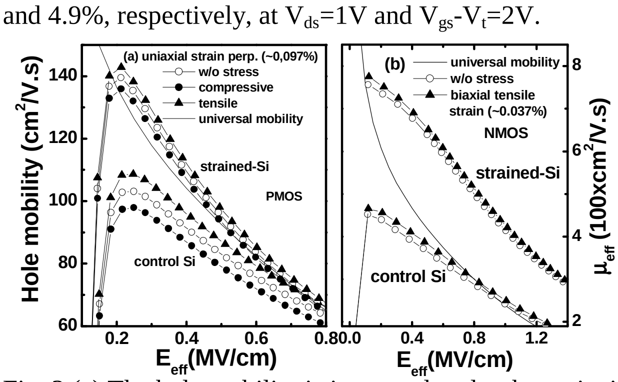

Fig. 3 (a) The hole mobility is increased under the uniaxial tensile strain for PMOS devices and (b) electron mobility of control Si (~3.5%) and strained-Si (~2.5%) is enhanced under the biaxial tensile strain on the NMOS devices with SiO_2 gate oxides.

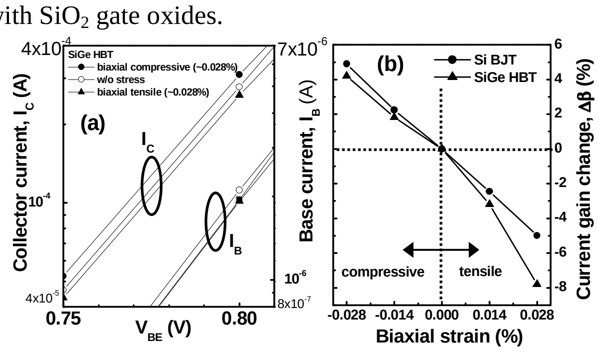

Fig. 4 (a) Gummel plot of SiGe HBT with and without bi-axial mechanical strain of ~0.028%, (b) the linear depend-ence of current gain changes for Si BJT and SiGe HBT after the strain.